



Drivers and trajectories of land cover change in East Africa: Human and environmental interactions from 6000 years ago to present

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ABSTRACT

East African landscapes today are the result of the cumulative effects of climate and land-use change over millennial timescales. In this review, we compile archaeological and palaeoenvironmental data from East Africa to document land-cover change, and environmental, subsistence and land-use transitions, over the past 6000 years. Throughout East Africa there have been a series of relatively rapid and high-magnitude environmental shifts characterised by changing hydrological budgets during the mid- to late Holocene. For example, pronounced environmental shifts that manifested as a marked change in the rainfall amount or seasonality and subsequent hydrological budget throughout East Africa occurred around 4000, 800 and 300 radiocarbon years before present (yr BP). The past 6000 years have also seen numerous shifts in human interactions with East African ecologies. From the mid-Holocene, land use has both diversified and increased exponentially, this has been associated with the arrival of new subsistence systems, crops, migrants and technologies, all giving rise to a sequence of significant phases of land-cover change. The first large-scale human influences began to occur around 4000 yr BP, associated with the introduction of domesticated livestock and the expansion of pastoral communities. The first widespread and intensive forest clearances were associated with the arrival of iron-using early farming communities around 2500 yr BP, particularly in productive and easily-cleared mid-altitudinal areas. Extensive and pervasive land-cover change has been associated with population growth, immigration and movement of people. The expansion of trading routes between the interior and the coast, starting around 1300 years ago and intensifying in the eighteenth and nineteenth centuries CE, was one such process. These caravan routes possibly acted as conduits for spreading New World crops such as maize (*Zea mays*), tobacco (*Nicotiana* spp.) and tomatoes (*Solanum lycopersicum*), although the processes and timings of their introductions remains poorly documented. The introduction of southeast Asian domesticates, especially banana (*Musa* spp.), rice (*Oryza* spp.), taro (*Colocasia esculenta*), and chicken (*Gallus gallus*), via transoceanic biological transfers around and across the Indian Ocean, from at least around 1300 yr BP, and potentially significantly earlier, also had profound social and ecological consequences across parts of the region.

Through an interdisciplinary synthesis of information and metadatasets, we explore the different drivers and directions of changes in land-cover, and the associated environmental histories and interactions with various cultures, technologies, and subsistence strategies through time and across space in East Africa. This review suggests topics for targeted future research that focus on areas and/or time periods where our understanding of the interactions between people, the environment and land-cover change are most contentious and/or poorly resolved. The review also offers a perspective on how knowledge of regional land-use change can be used to inform and provide perspectives on contemporary issues such as climate and ecosystem change models, conservation strategies, and the achievement of nature-based solutions for development purposes.

1. Introduction

There is little doubt that physical, biological and climatological systems have influenced the timing and trajectory of the development of human societies (Marchant and Lane, 2014). For example, the early to mid-Holocene was a time of profound cultural transition: settled agrarian societies emerged and were established across much of the world, a broad range of species were domesticated and their distribution ranges dramatically altered, new technologies were developed, and various complex societies emerged and collapsed. Given the evidence of complex spatial and temporal climatic variability in the Holocene, palaeoecologists and others question the extent to which human activities were the primary cause for many palaeoecological changes detected within the sedimentary record (Huntley, 1990; Ruddiman et al., 2015; Wright, 2017a). As more palaeoecological and archaeological records become available, it is apparent that the only constant in the Earth's climate is change, and that this change interacts with living populations as they develop and adapt.

An important contributing factor to all stages of hominid evolution that took place in Africa during the Plio-Pleistocene, was that of climatic change; this affected both hominid evolution and how humans have shaped and interacted with the environment (e.g., de Menocal, 1995; Deocampo et al., 2002; Maslin, 2016). Presently humans across the globe constitute the dominant controls on modifying ecosystem composition and distribution, and will continue to do so into the future. However, how ecosystem compositions and distributions have changed over time and space, and how both humanly-induced and environmentally-induced land-use changes have interacted, remain largely unresolved. Since people started to have more of a visible impact on their environments there has been little understanding of the

enmeshed nature of both the natural and cultural drivers of the temporal and spatial character of land-cover change. When palaeoecology is combined with archaeological data there is the potential to begin to empirically explore these past interactions by providing linked and extended time series that document various components of the living environment (Gillson and Marchant, 2014). Palaeoecological records provide perspectives on the long-term (decadal–millennial) scale of ecosystem changes; although these are often partial and discontinuous they do provide a ‘natural experiment’ framework for testing ecosystem responses to changing scenarios of climate, fire, and human impact (Deevey, 1969; Watts et al., 2016). The interpretative power of palaeoecological records increases dramatically when they are partnered with insights provided by archaeological evidence, particularly where there is tight chronological control.

Across East Africa, when investigating how climate change has impacted ecosystems and how those ecosystems have responded, sedimentary records have proven to be invaluable over a range of time scales (Graham et al., 2003). The historical fluctuations in lake levels across the region (e.g. Cohen et al., 1997; Gasse, 2000, 2002; Kiage and Liu, 2006; Street-Perrott et al., 2000; Verschuren et al., 2002) and ecosystem changes (Elenga et al., 2000; Finch et al., 2017; Hamilton, 1982; Mumbi et al., 2008; Mumbi et al., 2014; Rucina et al., 2009) have been well documented by various studies and demonstrate the sensitivity of East African ecosystems, in particular to moisture regime variability (Bollig, 2016; Vincens et al., 1999) and the ensuing interaction with secondary drivers such as fire (Colombaroli et al., 2014; Finch et al., 2017). Drought and flood episodes throughout the longer time span of the last 6000 years have been more dramatic and more persistent than those captured by the relatively short instrumental records available; the latter fail to capture the full spectrum of climatic

variability across the region (Gasse, 2000). Despite the clear value of available palaeo-archives understanding abrupt climate change in the past remains problematic (Overpeck and Webb, 2000). Understanding climate change remains of paramount importance, and to date, focus has been principally on the impacts of increasing global temperatures, ice sheet melting, and rising levels of atmospheric carbon dioxide (IPCC, 2014). However, there is great complexity in the processes and associated impacts of climate change, which are the results of interactions between changes in solar activity, atmospheric composition, atmospheric circulation, land-surface conditions, ocean currents, and human activities (Marchant and Lane, 2014).

Within the Global Change community there is an increasing recognition of the importance of the tropics for shedding light on complex climatic and environmental histories, as well as a growing understanding of how these histories interact with those of people through time. This review paper draws on this realisation to provide new insight into tropical ecosystem histories by collating available archaeological and palaeoecological evidence for cultural and environmental change across the East African region (Fig. 1). Research in East Africa has focussed on revealing cultural and environmental prehistory (Butzer, 1968; Marchant and Lane, 2014), as such it is an ideal test bed for investigating environmental-cultural dynamics, for discussing the interrelationships of these and for suggesting theories for the current correlations between the gathered palaeoenvironmental and archaeological data for the region from 6000 years before present (yr BP) (see

SM1 and SM2 for palaeoecological and archaeological site lists). Archaeologists and palaeoecologists are currently addressing the correlations in both types of data through the PAGES LandCover6k initiative (Gaillard and LandCover6k, 2015; Gaillard et al., 2015; Morrison et al., 2016), in particular addressing the seemingly interrelated connections between environmental change in the mid-Holocene and changes in land use seen across the world.

This review is a contribution to the PAGES LandCover6k initiative, for both its “land cover” and “land use” activities. These activities have the goal of achieving pollen-based reconstructions of Holocene land-cover/plant-cover change and archaeological/historical reconstructions of land-use types and quantifiable attributes such as intensity of irrigation, wood harvesting, use of fire, etc. (e.g. Gaillard and LandCover6k, 2015; Morrison et al., 2016). The major aim of these reconstructions is to provide empirical information on anthropogenic land-cover change to climate modellers for the study of climate-vegetation interactions over time (e.g. Strandberg et al., 2014). For this review, our approach will be based on synthesizing palaeoenvironmental and archaeological evidence to provide a timeline of land-cover change from 6000 yr BP to present. The review will therefore explore the spatial and temporal linkages between East African societies and environmental change. The review is organised into six main sections; following this introduction, section two introduces the East African region. This is followed by the third section where a synthesis of the types of evidence for environmental change since 6000 yr BP is made in

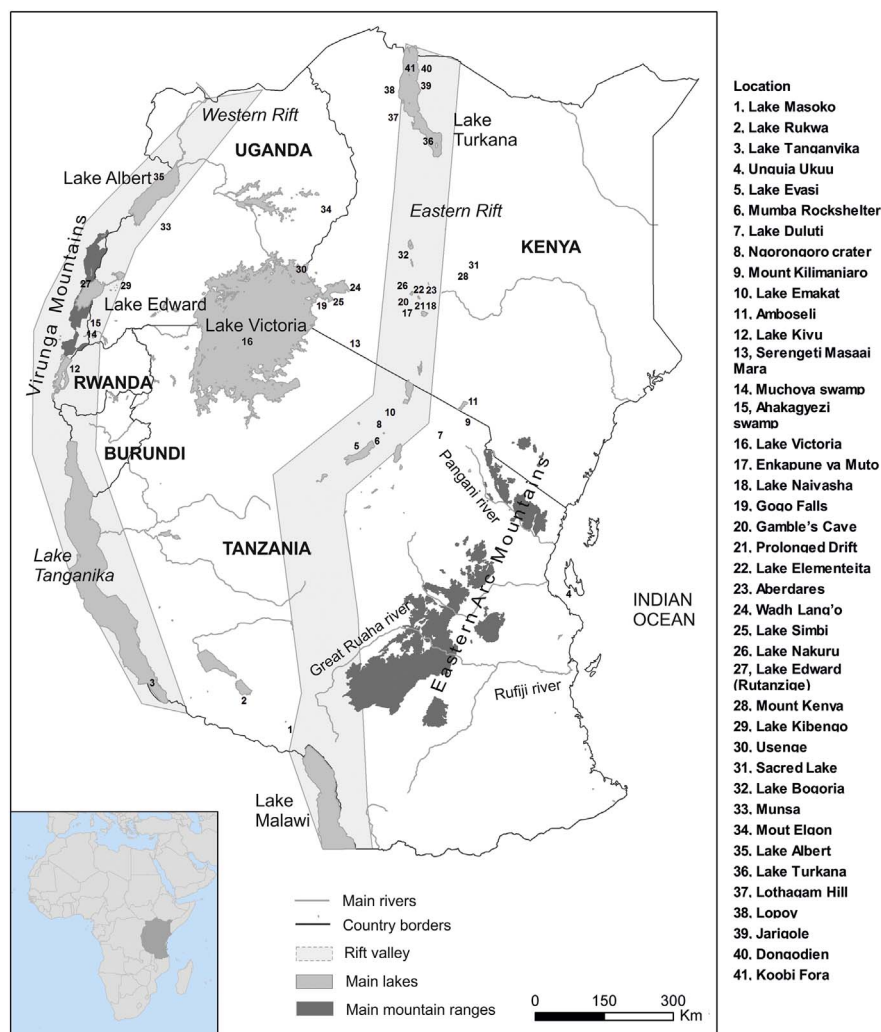


Fig. 1. Equatorial eastern Africa and study site locations and geographic features discussed in text. Eastern Arc Mountains delineated according to Platts et al. (2011). See Table 1 for a list of numbered site locations.

four subsections. The archaeological evidence for cultural change for the same time periods is also reviewed here. The fourth section investigates possible interconnections between the evidence from archaeological and environmental data, while also discussing the challenges of linking these data and inferring cultural environmental interrelations. The fifth section investigates the utility of information of

past land-cover change in a number of areas such as ecosystem modelling, biogeochemical cycling, ecosystem services and conservation. The final section discusses developing methodologies and areas for targeting future research activity in the context of our current understanding of changing land cover across the East African landscape. Throughout the text, ages are expressed in calibrated years before

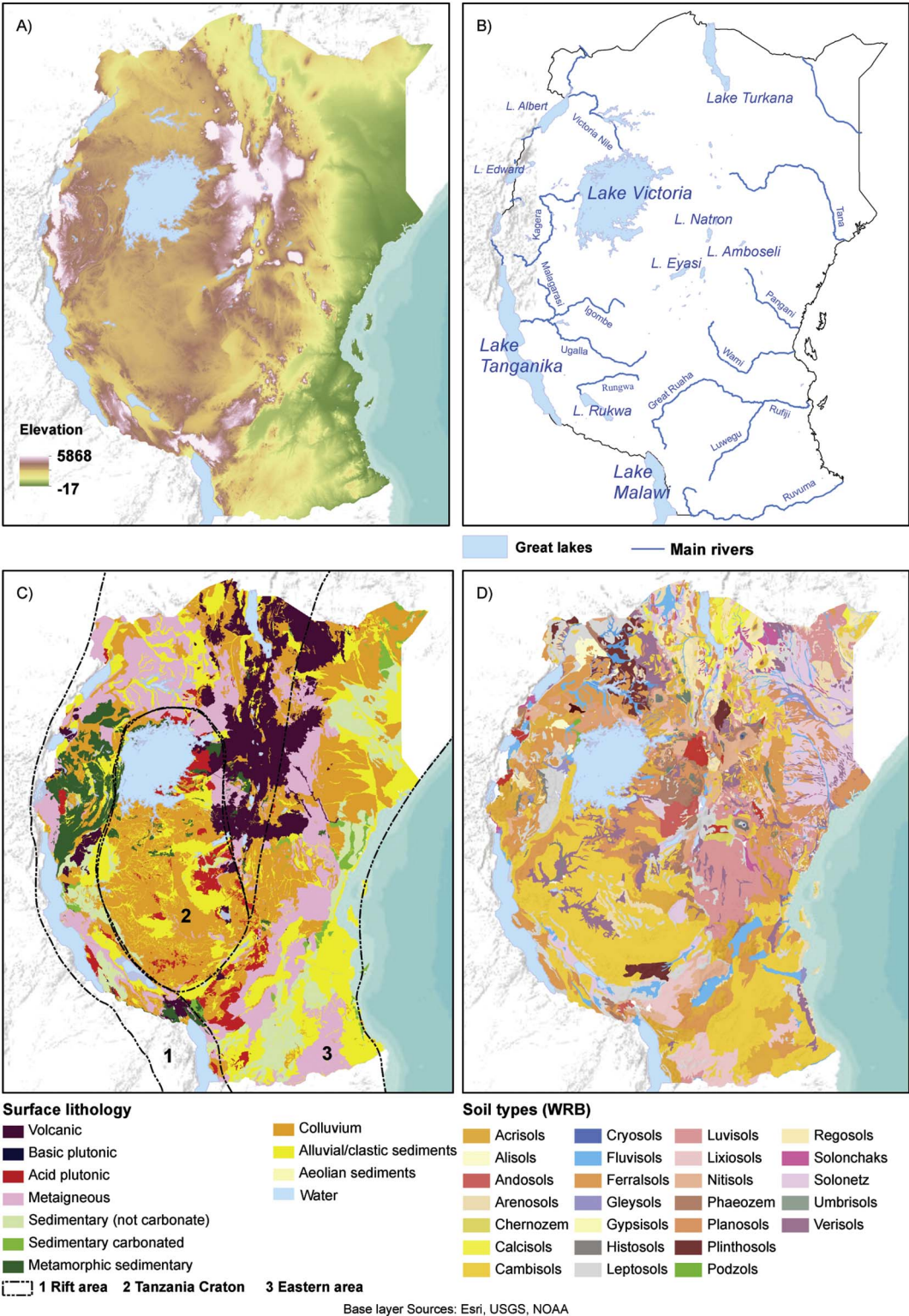


Fig. 2. Plots of the study area by: A) elevation derived from the SRTM-250 m Digital Elevation data (<http://srtm.csi.cgiar.org>). B) hydrology derived from the Natural Earth river datasets and the DIVA-GIS water areas datasets. C) lithology derived from the African Surface Lithology map (SERVIR RCMRD). D) soil types derived from the Soil Atlas of Africa, World Reference Base classification, (Dewitte et al., 2013).

present (yr BP) except for specific recent or historical-period dates, which are given as Common Era (CE).

2. The East African Interlacustrine region

For the purposes of this review, the East African Interlacustrine region comprises the countries of Kenya, Tanzania, Uganda, Rwanda, and Burundi that surround Lake Victoria (Fig. 1). To provide context, the present-day key environments and ecosystem types found in East Africa will be detailed.

2.1. Climate systems in East Africa

The climatological patterns in East Africa are highly complex due to the superimposition of major convergence zones upon regional feedbacks, which are in turn associated with the lakes and the varied topography that dominate the region (Figs. 2 and 3). The equatorial location of the study area also means that the climate is governed by air circulation and precipitation driven by the Inter-Tropical Convergence Zone (ITCZ) and associated monsoon front over the Continent. Other regional climate systems include the Congo Air Boundary (CAB; Costa et al., 2014) (with airflows from the west and southwest), and the northeast (NE trade winds) and southeast (SE trade winds) monsoons.

The ITCZ is directly linked to the meeting of the trade winds from both hemispheres, however, the subtropical high-pressure cells that are

located 20–30° north and south of the equator, shift with the seasons (Nicholson, 1994, 1996a, 2000). The region experiences a twice-yearly passage of the low-pressure ITCZ, and whilst it is linked with the seasons it also lags behind the zenith position of the sun by approximately 1–2 months (Ogallo et al., 1988). As the passage of the ITCZ changes with the seasons it creates a strongly bimodal pattern of seasonal rainfall, although this exhibits considerable variation across the region (Fig. 3C) (Bergonzini et al., 2004). The northern and southern parts of East Africa experience unimodal rainfall regimes during June to August and during December to February respectively. The Lake Victoria Basin and Eastern Rift Valley experience a third rainfall regime during the northern Hemisphere summer (June–August) when the zonal and the meridional arms of the ITCZ are displaced to the north and east resulting in enhanced convergence of moist air mass from the Congo Basin (Ogallo et al., 1988). Combined effects of the Lake Victoria trough and the highlands west of the Rift Valley also contribute to the third rainfall peak (Omeny et al., 2008). For much of equatorial East Africa, monsoonal winds from the southeast in March to May bring long periods of rain (Yang et al., 2015). In comparison, the rainy period in October to December, brought in by the northeasterly monsoon, is generally shorter. The combination of these two rainy periods accounts for the majority of equatorial East Africa's annual rainfall. However there can be large interannual variability to the point where one or more of the rainy seasons can fail (Nelson et al., 2012), and the amount of short-season precipitation in any given year yields little to no

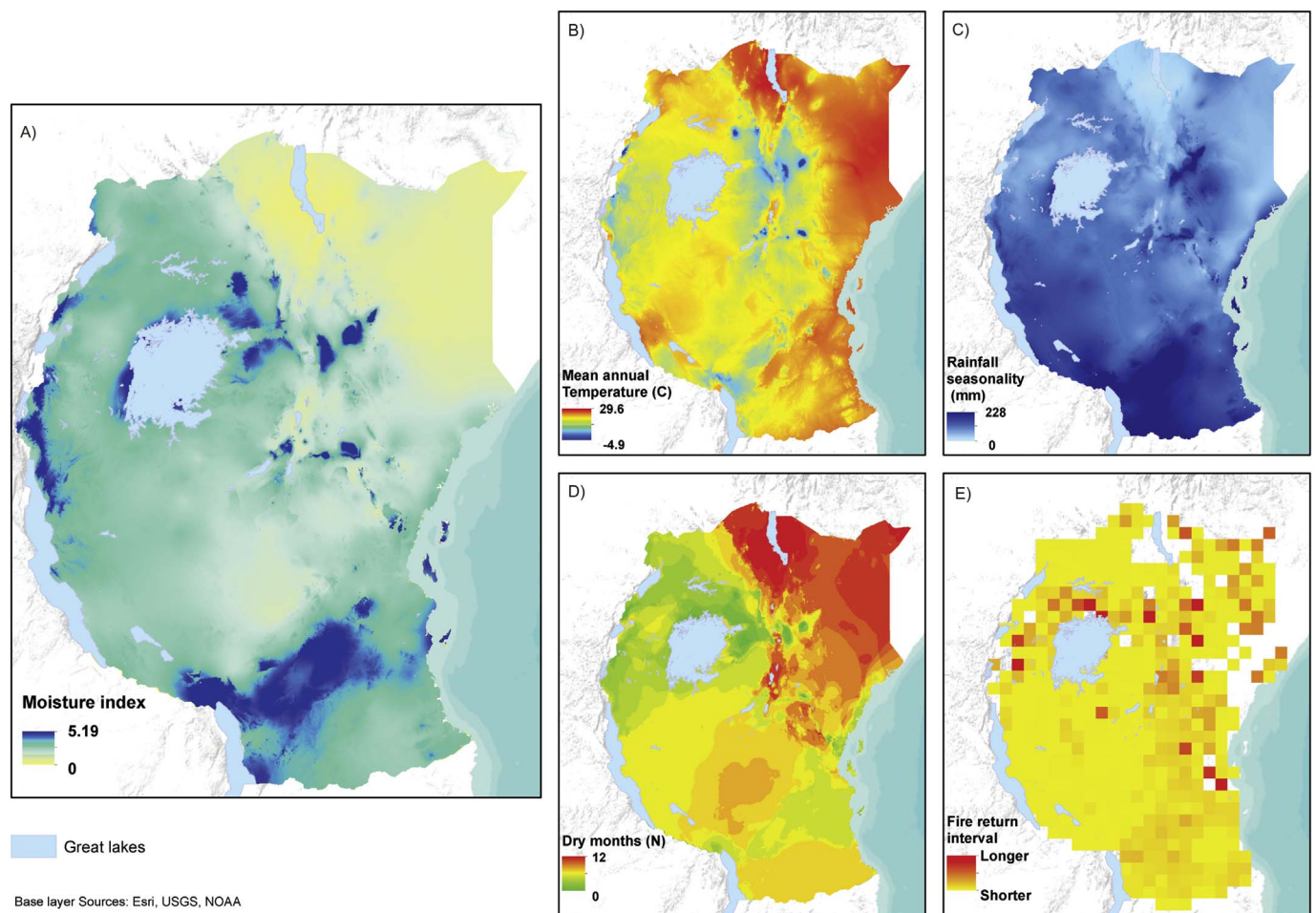


Fig. 3. Plots of climate and fire parameters over the study area. Climate parameters based on WorldClim (Hijmans et al., 2005) as derived by AfriClim 3.0 (Platts et al., 2015): A) moisture index, calculated as the ratio between total monthly rainfall and potential evapotranspiration. B) mean annual temperature (mean of January–December monthly means). C) precipitation variability (standard deviation of monthly precipitation). D) number (N) of dry month per year. E) Mean fire return intervals calculated using the MODIS active fire product MCS14ML from April 2000 to June 2015 through a flood-fill algorithm to identify individual fires for the continent south of 10° North latitude (Archibald et al., 2010) to establish time since last burn (the log transformed mean number of days since an earlier fire for all pixels in the fire; fire return interval or FRI) at 30 arc-minute spatial grain (Hempson et al., 2017).

predictive power over the following long rains (Lyon, 2014).

The major characteristic of current climate change across the tropics is increased rainfall variability manifesting as changes in precipitation (intensity, duration and timing). It has been challenging to reproduce rainfall variability within climate models, particularly for East Africa where rainfall is influenced by a range of large and local-scale drivers and feedbacks. Much of the variability that occurs during the short rainy season is linked to large-scale climate systems such as the El Niño–Southern Oscillation (ENSO) (Ogallo et al., 1988; Mutai and Ward, 2000; Indeje et al., 2000) and the Indian Ocean Dipole (IOD) (Saji et al., 1999; Behera et al., 2003; Schreck and Semazzi, 2004; Behera et al., 2005; Owiti et al., 2008; Marchant et al., 2007; Tierney et al., 2013; Cai et al., 2014). At the intra-seasonal timescale, different phases of the Madden-Julian Oscillation (MJO) are linked to modal wet and dry periods over equatorial eastern Africa (Pohl and Camberlin, 2006; Omeny et al., 2008) that consist of three to four 10-day duration anomalous rainfall events totalling 100–150 mm followed by prolonged dry spells (Kabanda and Jury, 2000). Opposite phase relationships exist between the west and the east of equatorial eastern Africa (Omeny et al., 2008). Tropical cyclones over the Indian Ocean contribute to intra-seasonal events indirectly by creating a west–east pressure gradient resulting in enhanced rainfall over much of the western and central equatorial sub-region of East Africa and contrasting dry conditions over the eastern equatorial sub-region (Shanko and Camberlin, 1998). Topographical variation associated with the Great Rift Valley and large inland water bodies (e.g. Lake Victoria) greatly influence the spatial distribution of seasonal rainfall in the region, especially the March–May long rainy season (Nykwada et al., 2009). The western highlands tend to be wetter due to advection of moisture from the south-westerly winds and Congo air mass, while the eastern highlands tend to be wetter during the short rainy season (October–December) due to moisture advection from the Indian Ocean associated with north-easterly winds (Oettli and Camberlin, 2005).

Atmosphere, insolation, vegetation and moisture all interact on diurnal and longer timescales, crucially influencing the environmental conditions of the isolated massifs and mountain chains of East Africa (Figs. 1, 2 and 3). As water towers, mountains provide critical connections to the more arid lowlands (Rucina et al., 2009; Cuni-Sanchez et al., 2016). Climatic variations with altitude are complex, resulting from various factors superimposed on the general climatic regime described above. This factor can be summarised as an adiabatic lapse rate. Although lapse rates have often been ‘determined’ from altitudinal changes in temperature (Marchant and Hooghiemstra, 2004), results vary considerably and are known to change through time (Loomis et al., 2017). One standard that is constant is the dry adiabatic lapse rate; this can be defined as the cooling of an absolute dry parcel of air as it passes to higher altitudes due to changes in pressure (Barry and Chorley, 2009). The laws of thermodynamics fix this rate of cooling at $-9.8^{\circ}\text{C } 1000\text{ m}^{-1}$. However, cooling air invariably produces condensation, and the liberalisation of latent heat, which reduces the rate of temperature decrease (Barry and Chorley, 2009). The saturated adiabatic lapse rate varies considerably with ambient temperature; at high temperatures the rate can be as low as $-4^{\circ}\text{C } 1000\text{ m}^{-1}$, and increases with decreasing ambient temperature to approaching $-9^{\circ}\text{C } 1000\text{ m}^{-1}$ at -40°C (Barry and Chorley, 2009). Thus, the actual adiabatic lapse rate, or environmental lapse rate, varies according to levels of ambient moisture and temperature and the environmental lapse rate commonly used for eastern and central Africa ($-6.5^{\circ}\text{C } 1000\text{ m}^{-1}$; Kenworthy, 1966) is likely to vary according to aspect, topography, radiation balance, and to have been different under past climatic regimes (Nicholson et al., 2013; Loomis et al., 2017). Thus, caution is prudent when applying lapse rates to time points in the past, or indeed different areas from where the rate was computed.

2.2. East African geology, topography and drainage

Since the Precambrian, the rocks currently making up the African continent have been less conspicuously affected by the major global epochs. This geologic stability, relative to other continents, has resulted in a gentle topography for much of the African continent. However, East Africa has undergone tectonic dislocation, beginning in the Mesozoic (Chorowicz, 2005; Summerfield, 2005; Braile et al., 2006; Macgregor, 2015), which resulted in the formation of the Western and Eastern Rift Valleys (Fig. 1) with uplift ranging from 700 m asl (metres above sea level) to over 4000 m asl (Hamilton, 1982; Calais et al., 2006). The most active tectonic phase took place from mid-Tertiary times, particularly centered around 22, 6 and 2.5 million years ago (Grove, 1989; Maslin et al., 2014), and was accompanied by extensive volcanism which produced many of the singularities of the East African topography. This is the case of the Virunga volcanoes in northern Rwanda and western Uganda, which originated during the Quaternary period and mark the hydrological divide between the headwaters of the Congo and Nile river systems. Similarly, Kilimanjaro and Mount Kenya are relatively new features on the landscape originating from the early Quaternary period. In contrast to this volcanic activity, the Ruwenzori and Eastern Arc mountains were formed by upthrust of Precambrian crystalline rocks (Schlüter, 2008). Tectonic activity also produced the high plateau that characterises much of East Africa (Fig. 2). Most of the tectonic uplift had occurred before the start of the Quaternary glaciations (Karlén et al., 1999), with each phase of uplift the associated erosion and deposition of the uplifted geology resulted in the topographically complex landscape that we see today as the East African Rift System (EARS) (Figs. 1, 2A and C). One of the characteristic features of East Africa is the numerous lakes located along the EARS (Trauth et al., 2007, 2014). Towards the south of the region, Lake Tanganyika dominates a chain of large, deep lakes (Kivu, Edward and Albert) along the floor of the western (Albertine) branch of the EARS from south to north (Fig. 1). The many lakes that occupy the eastern (Gregory) Rift Valley are typically smaller and shallower. The rifting process has also had considerable effect on central African watersheds outside of the main centres of rifting (Walling, 1999), for example, resulting in a reversal of previously west-flowing rivers, thereby creating Lake Victoria between the Albertine and Gregory Rift Valleys (Street and Grove, 1975) (Figs. 1 and 2B).

2.3. Soils and edaphic factors influencing ecosystem composition in East Africa

The diversity and distribution of soil types in East Africa result from the range of geological and climatic conditions of the area acting upon a tectonically modified topography (Fig. 2D). According to Bamutaze (2015), 25 soil types are represented in this area, demonstrating a large pedodiversity when compared to the 29 types that have been identified by Dewitte et al. (2013) for continental Africa as a whole. For the purpose of this soil description, the study area is divided into three broad units following topographic and lithologic criteria: The Rift Valley area, the Tanzanian Craton, and Eastern Kenya and Tanzania; and soil types are designated according to the World Reference Base classification system (IUSS, 2015) (Fig. 2C and D).

2.3i. Rift Valley Area

The Rift Valley formation dominates the soils distribution to the west (Fig. 2C and D). There, the most common pedogenetic process is the formation of Fluvisols (e.g., Sakané et al., 2011), young soils developed in alluvial deposits with a weak horizon differentiation, but usually fertile and productive (IUSS, 2015). In locations with high evapotranspiration rates saline soils appear, such as Solonchacks and Solonetz soil types (Fig. 2D). In the semi-arid basin of Lake Turkana, for example, where 15–20% of the rangelands are affected by soil salinity, high temperatures and low precipitation rates also produce large

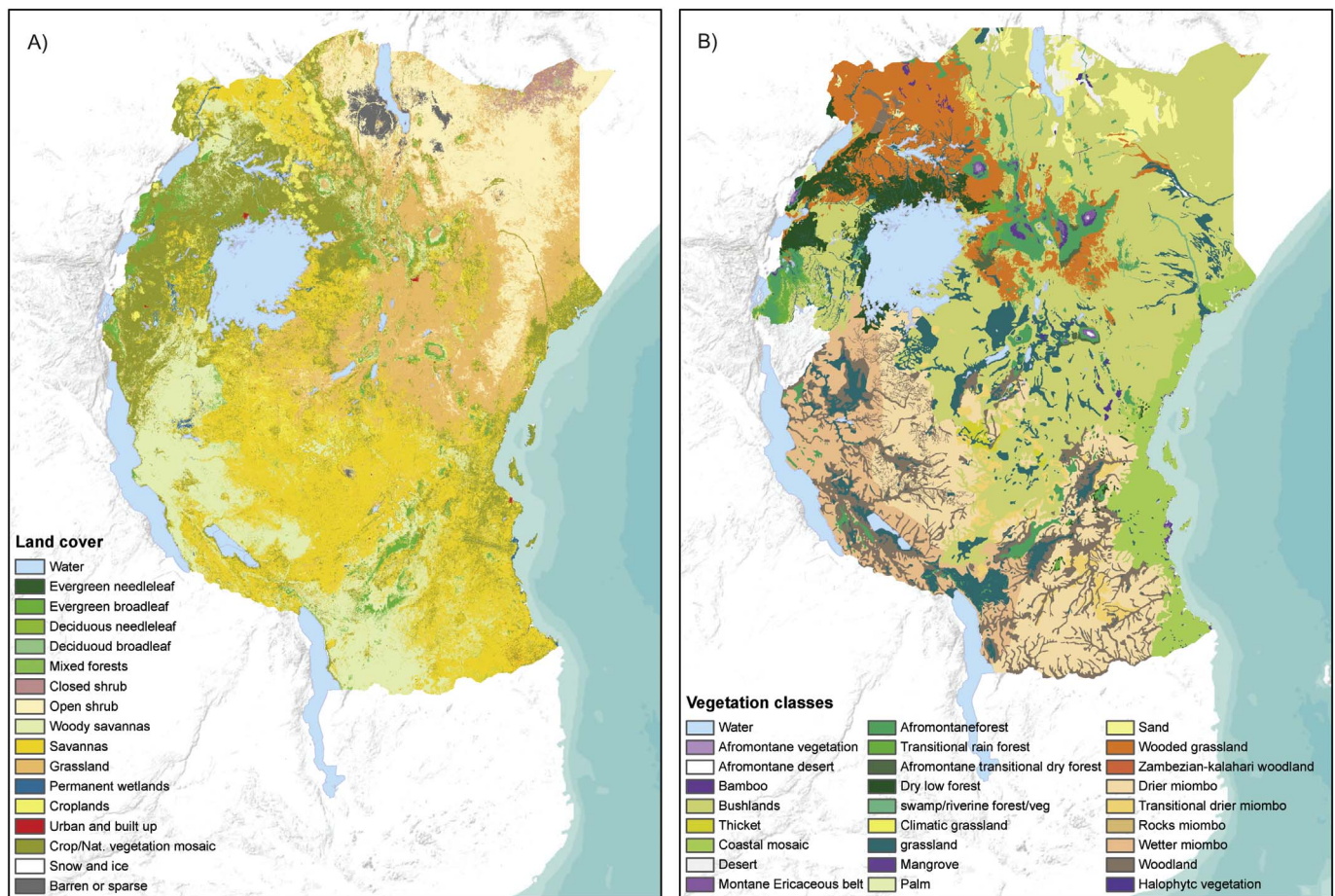
extensions of Calcisols, sodic Solonetz and weakly developed Regosols (Mace, 2012; Mbaluka and Brown, 2016).

On either side of the Rift Valley, elevation increases steeply from around 600 m to a high plateau (1000–1500 m asl) and a number of volcanic peaks exist, both features linked to the rifting process (Trauth et al., 2007; Schlüter, 2008; Maslin et al., 2014). In this area, weathering of volcanic materials (basalts, ash and lava deposits) produce fertile and sandy-loam Andosols with a thick, dark and organic rich topsoil as a result of the accumulation of organic matter and the formation of noncrystalline materials (Funakawa et al., 2012; Matus et al., 2014; Mizota et al., 1988; Shoji et al., 1993). On the slopes of the volcanoes, fertile Nitisols are also frequent. These are well known for coffee and tea production in, for example, the Kenyan Highlands (Kikuyu Red Clays; e.g. Kapkiyai et al., 1999; Lal, 2010), which are one of the most intensive agricultural production regions in East Africa. Nitisols develop mainly from basic iron-rich rocks such as basalt, and have a dark red colour and a well-developed structure (Wanjogu et al., 2003; Karuku et al., 2012). However, the large reactive aluminium and iron contents in both Andosols and Nitisols frequently result in a large phosphate-fixation capacity and therefore a low phosphorous availability to vegetation (Nandwa and Bekunda, 1998; Batjes, 2011; Kisinyo et al., 2013; Verde and Matusso, 2014; Nziguheba et al., 2016). Considerable extensions of Ferralsols in Uganda, Rwanda and Burundi are the result of large weathering intensity due to high rainfall (Bekunda et al., 2002; Verdoodt and Van Ranst, 2006; Gray, 2011; Wasige et al., 2014; Musinguzi et al., 2015; Shi et al., 2015; Syldie, 2017). Ferralsols are capable of supporting climactic rainforest ecosystems, as a result of a fast turnover of organic matter and nutrients.

However, they are fragile, not resilient soils, and can be easily degraded under deforestation processes (Nyombi et al., 2010; Bamutaze, 2015; Oyana et al., 2015).

2.3ii. The Tanzanian Craton

The central unit includes the uplifted Archaean Tanzanian Craton (WoldeGabriel et al., 2016), characterized by a more acidic and predominantly plutonic and sedimentary lithology, and a flatter topography (Fig. 2A, C and D). The Lake Victoria Basin, the Serengeti and Mara Plains and the west of Tanzania are included in this area, which is partially limited to the east by the eastern branch of the Rift Valley and the Ngorongoro Conservation Area (Dawson, 2008; Schlüter, 2008; Selway, 2015; Kasanzu, 2016). In the northern part of this area, Planosols are frequent, mainly in the Lake Victoria Basin (Lufafa et al., 2003; Rwetabula et al., 2012). These are poorly drained soils with a high clay content in the subsoil that may impede or limit drainage, resulting in poorly structured topsoils (Biamah, 2005; IUSS, 2015). Also in the Lake Victoria Basin and interspersed with Planosols, are vast areas of clay-rich Vertisols (Sakané et al., 2011) and Luvisols (Lufafa et al., 2003) that develop preferentially on the level ground of river valley floors. These are naturally productive clay-rich soils that form deep, wide cracks upon drying, due to the presence of shrinking and swelling clays. In the extensive grasslands of the Serengeti and Mara Plains, the predominant soils are organic and lime-rich Phaeozems (Blake et al., 2008). In western Tanzania, in turn, the more acidic lithology is reflected in extensive areas of less developed Cambisols, with Vertisols forming only in the river valleys, related to sedimentary deposits formed by weathered volcanic materials (Sakané et al., 2011).



Base layer Sources: Esri, USGS, NOAA

Fig. 4. Plots of land cover. A) derived from MODIS data for 2013 (Channan et al., 2014; Friedl et al., 2010). B) potential natural vegetation of eastern Africa (van Breugel et al., 2015a, 2015b).

2.3iii. Eastern Kenya and Tanzania

To the east, the topography drops in elevation. A large, predominantly sandy plain extends towards the Western Indian Ocean coastline, where the terrain is dissected by deep valleys and predominantly sandy surfaces running down towards the coast. The coarse grained material gives rise to Arenosols and red coloured Ferralsols (Fig. 2D) (Gichangi et al., 2015; Hartemink and Hutting, 2005; Mganga et al., 2015), while the evaporation of saline groundwater originates from the widespread occurrence of Solonetz (Omuto, 2013). In the central part of Kenya, Lixisols develop in areas with a pronounced dry season (Omuto, 2013). In eastern Tanzania, in turn, the Mozambique Belt conditions the lithology and is responsible for a steeper topography (Schlüter, 2008; Selway et al., 2014; WoldeGabriel et al., 2016). Luvisols developed on the metamorphic and sedimentary rocks where the relief is more pronounced; for example, Kilimanjaro and Pare and Usambara Mountains (Mizota et al., 1988; Rwehumbiza et al., 1999; Msanya et al., 2002; Gachimbi, 2002; ISRIC, 2006; Pachpute et al., 2009; Mathew et al., 2016). These soils have a distinct increase in clay content with depth as a result of clay illuviation, a well-developed soil structure and a high water and nutrient-holding capacity (IUSS, 2015). Farther south, the undulating topography and the lithological variation of the parent materials has resulted in a mosaic of soil types. Extensive areas of Fluvisols and dark, clayey Vertisols developed in alluvial sediments of the river systems of central Tanzania, such as the highly productive Rufiji River floodplains and the Ruaha River wetlands (Karlsson and Messing, 1980; Majule, 2012; Jones et al., 2013; Armanios and Fisher, 2014; Mbungu and Kashaigili, 2017). Fertile

Nitisols and more acidic Acrisols occur on gentle slopes, their distribution depending on underlying lithology (Lyon et al., 2015). Continuing southwards, increasing aridity and the predominance of grasslands and savannah (Dondéyne et al., 2003, 2004) gives rise to extensive Lixisols and Cambisols (Msanya et al., 2002).

2.4. East African ecosystem composition and distribution

Throughout this paper common names and binomial nomenclature are used at first mention, further references may be in the form of common or scientific names depending on the context. We use ‘acacia’ to mean the African acacia trees of the *Vachellia* and *Senegalia* genera (Fabaceae: Mimosoideae). The vegetation of East Africa (Fig. 4) is currently influenced by human land use (Fig. 4A) but still reflects the climatic regime, with topography, and the amount and seasonality of precipitation, being particularly important in determining ecosystem composition, structure and distribution (Fig. 4B). Additionally, edaphic and disturbance regimes impart important local controls, particularly in grassland, savannah and forest boundaries. Six major vegetation communities (phytochoria) can be delineated in East Africa (Lind et al., 1974; White, 1983) (Fig. 3), consisting of mangrove, coastal rainforest, open savannah grasslands, wooded savannah, (Fig. 5), montane forest and Ericaceous scrub (Fig. 6). A relatively thin strip of mangrove forest is present within the tidal coastal strip (Fig. 5A) (Punwong et al., 2013a, 2013b, 2013c) that quickly grades into coastal rainforests (Fig. 5B); the latter, now fragmented, are a globally recognised hotspot of biological diversity (Burgess et al., 1998a). Many species are endemic to the

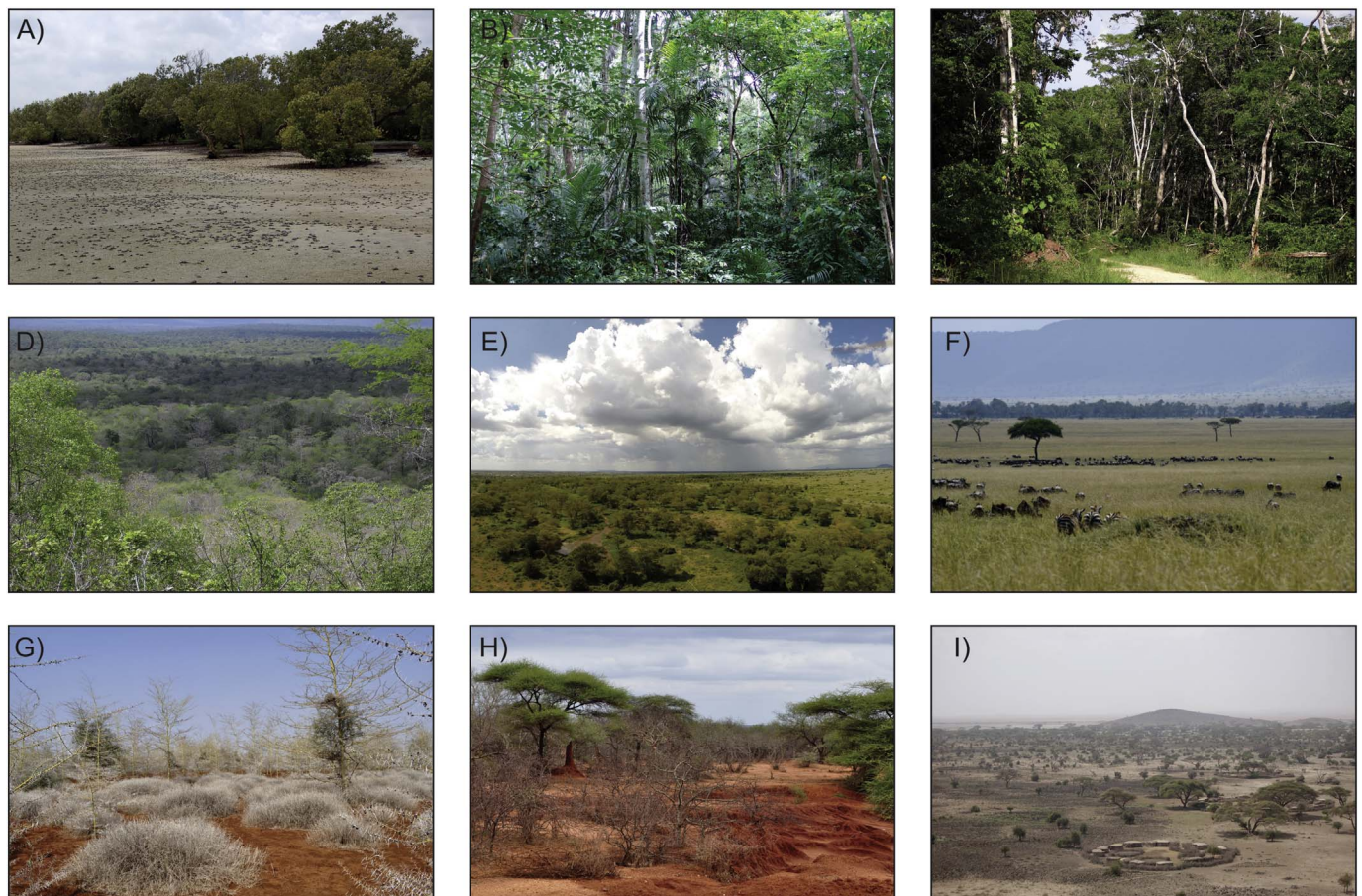


Fig. 5. Biomes of eastern Africa. A) Coastal mangrove forest on intertidal mudflats (photo: Rob Marchant). B) Coastal Ngezi forest with endemic palm on Pemba Island (photo: Neil Burgess). C) Pindi forest in Kilwa (photo: Neil Burgess). D) Miombo woodlands at Kilwa looking over Selous (photo: Neil Burgess). E) Kimana wetland and acacia (*Vachellia xanthophloea*) forest embedded within the semi-arid savannah landscape (photo: Colin Courtney-Mustaphi). F) Continuous grassland savannah with intermittent trees (photo: Rob Marchant). G) Northern Kenya acacia woodland (photo: Rob Marchant). H) Northern Kenya acacia-*Brachystegia* shrubland-woodland (photo: Rob Marchant). I) Woody savannah pastoral landscape, close to Amboseli national Park (photo: Rob Marchant).

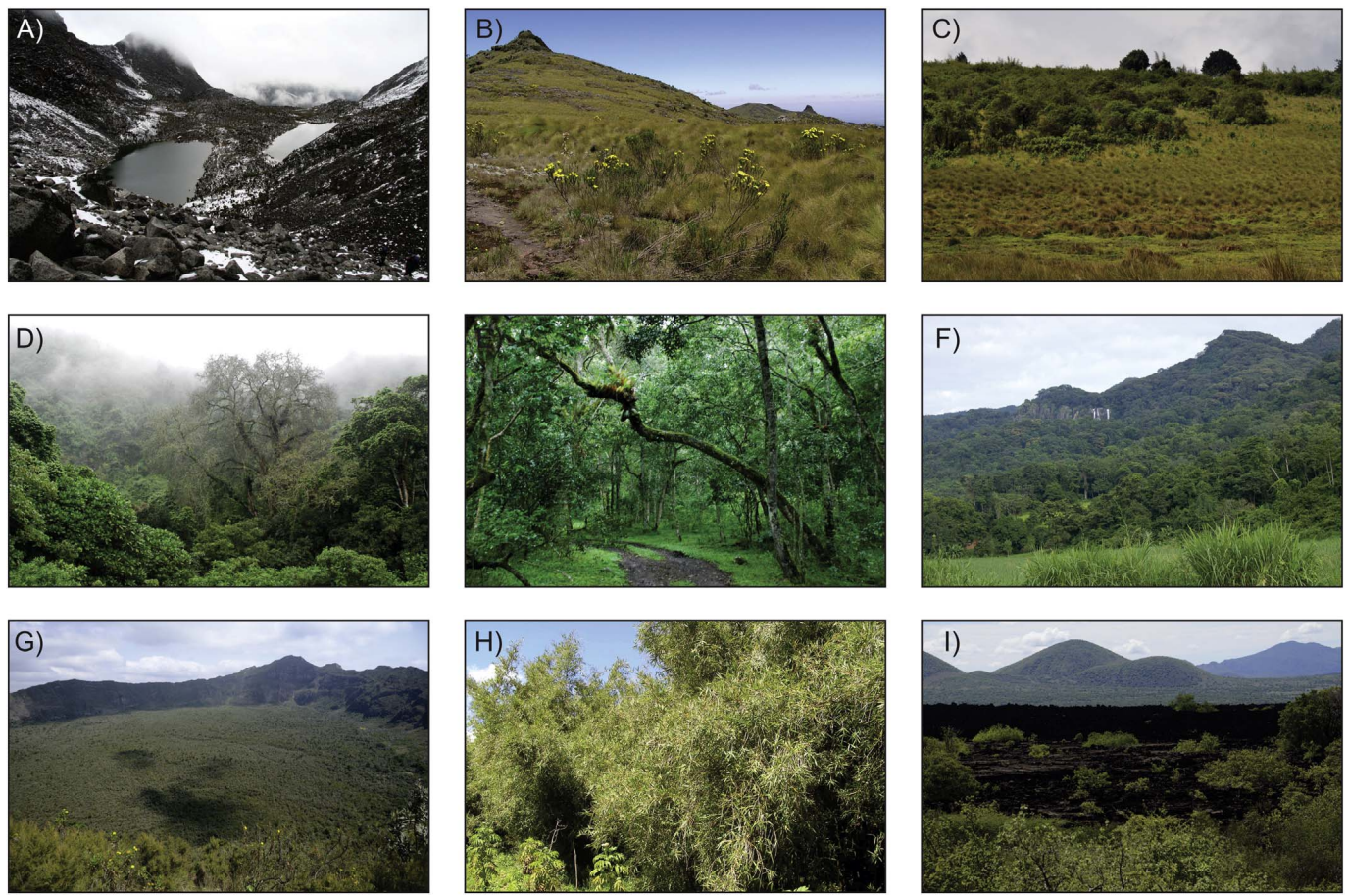


Fig. 6. Mountainous biomes of eastern Africa. A) high alpine bare-ground sparse low-lying vegetation cover, head of Hausberg Valley, Mount Kenya (photo: Hilde Eggermont). B) Continuous alpine vegetation, Mount Satima, Aberdare (photo: Rob Marchant). C) Ericaceous vegetation, Kilimanjaro (photo: Rob Marchant). D) Montane fog forests, important to biodiversity and complex atmosphere-vegetation hydroclimatic interactions, Arusha National Park, Mount Meru, Tanzania (Photo: Colin Courtney-Mustaphi). E) Epiphytic moist montane forest, Arusha National Park, Mount Meru, Tanzania (photo: Rob Marchant). F) Moist montane forest Mount Kenya (photo: Rob Marchant). G) Lower montane forests in Mount Longonot crater (photo: Rob Marchant). H) Bamboo forest on Mount Elgon (photo: Rob Marchant). I) young deciduous woodland forest atop recent basalt flows at the footslopes of Chyulu Hills, Kenya (photo: Colin Courtney-Mustaphi).

coastal forests, for example 44% of plants are endemic and 40% of plant genera are confined to a single forest patch. Unfortunately, coastal forests have been the target of logging over the past centuries and, along with the relatively restricted mangrove forests, have been intensively impacted. Coastal forests currently cover around 5% of their original extent with extant forests confined to forest reserves or under community-protected 'kayas' in Kenya (Tabor et al., 2010; Ming'ate and Bollig, 2016).

Decreasing precipitation with distance to the coast leads to the remnant patches of coastal forest grading into savannah (Fig. 5F). The composition and structure of East African savannahs have been largely shaped by a long and interwoven history of interaction with climatic, animal and anthropogenic factors, which include fire and herbivores as main drivers. As such, and given their extensive distribution across East Africa, savannahs deserve a special place in this review. The development of savannahs occurs where climatic conditions, vegetation and disturbance regimes interact to counteract factors that promote woody plant growth and lengthening of disturbance intervals (Lehmann et al., 2011). Edaphic controls are regionally important to savannah distributions. Whilst 'savannahs' vary regionally, they are characterised by the continuous cover of grasses and an open canopy of drought-, fire- or browser-resistant trees. An ecosystem dominated by *Acacia-Commiphora*, consisting of a heterogeneous tree and shrub layer and an herbaceous matrix dominated by C_4 grasses (Fig. 5I) is an example of a savannah ecosystem. Savannahs are often characterised by areas of dense thicket interspersed with more open, park-like vegetation and

maintained by edaphic, fire and/or herbivore influence (Fig. 5E–I). For example, edaphic savannahs (e.g., the grass savannah of southeastern Serengeti), form on free-draining substrates where the growth of hydrophilous trees is restricted. Fires, both natural and anthropogenic, occur frequently and have led to the dominance of plants adapted to survive regular and periodic burning (Carcaillet et al., 2002). Whilst people have interacted with savannahs for millennia, contributing substantially to their contemporary composition and distribution (Reid, 2012), the third main control on savannahs is herbivory - the act of eating plants by an herbivore - in this instance by large mammals. Whilst the African savannah is home to the world's greatest diversity of ungulates, where numerous species coexist (Arsenault and Owen-Smith, 2002; Hopcraft et al., 2010; Sinclair et al., 2010), it is largely elephants that maintain the open woodland structure. They do this by debarking and knocking over trees, which has the effect of 'opening' the woodland and allows grasses to invade. This, in turn, attracts more grazing animals of greater variety into the area in question. Species of shrubs and trees with defensive thorns and hooks establish themselves in clearings, leading to thorny thickets that exclude grazers. Common trees and shrubs to savannah ecosystems include *Grewia* spp., *Lannea* spp., *Newtonia hildebrandtii*, *Premna resinosa*, *Salvadora persica* and *Terminalia* spp. amongst these, larger trees are often scattered, such as *Adansonia digitata*, *Balanites aegyptica*, *Delonix elata*, *Kigelia africana* and *Melia volkensii* (Gillson, 2015). Moving up the altitudinal gradient, around 1600 m asl savannah woodland grades into lower montane forests dominated by semi-drought-deciduous trees and shrubs (Fries and Fries, 1948;

Herlocker and Dirchl, 1972). These forests are primarily composed of taxa such as: *Celtis* spp., *Urticaceae*, *Myrtaceae*, *Croton* spp., *Holoptelea* spp., *Prunus africana*, *Podocarpus milanjianus* and *Ilex mitis* (Bussmann, 1994).

Montane vegetation belongs to three broad ecosystems: Afroalpine, Afromontane and Guineo-Congolian (White, 1983) are regional divisions of vegetation, based upon floristic composition and distribution. There is a noticeable altitudinal overlap between the groups - and significant variation within the groups - leading to numerous descriptions of sub-divisions. Hedberg (1951) classified vegetation into a series of belts (regionally recognisable vegetation associations), and zones (locally based altitudinal bands); in ascending order these are the montane forest belt (Fig. 6D–F), the ericaceous belt (Fig. 6B and C) and the Afroalpine belt (Fig. 6A). These broad vegetation associations are characterised by complex plant distributions that are not simply restricted by elevation zonations and that reflect long and complex dispersal and disturbance patterns (Hemp, 2006). Montane forest (3300–1600 m) comprises broad-leaved, hardwood trees, and less frequently conifers (Hamilton, 1982). However the zoning is not straightforward; several different zones are recognised, different scholars use different terminology for similar zones, different “transitional altitudes” are delimited between the zones, and many taxa are distributed across these “zones” (Eggling and Dale, 1951; Hedberg, 1951, 1954; Langdale-Brown et al., 1964; Livingstone, 1967; Chapman and White, 1970; Lind et al., 1974; White, 1983). Indeed, Boughey (1955) identified a total of thirty-nine different synonyms for montane forest.

This plethora of terms has led to confusion, and possible misinterpretation, of data on montane vegetation distribution.

Here we adopt the classification for East African montane vegetation first proposed by Hamilton (1982), where montane forest is divided into lower and upper altitudinal zones, the adjectives moist and dry being used where appropriate. At lower altitudes, the forest has structural and floristic similarities to lowland forest, although it is more species rich than the dry lower montane forest (Chapman and White, 1970). The vegetation is dominated by *Celtis* spp., *Juniperus procera* and *Olea capensis* ssp. *hochstetterii*. For the moist lower montane forests, on the lower slopes of valleys, frequent species include *Entandrophragma excelsum*, *Neoboutonia macrocalyx*, *Parinari excelsa* and *Syzygium cordatum*. In the mid-altitudes *Cassipourea ruwensorensis*, *Chrysophyllum albidum*, *Drypetes albid*, *Ilex mitis*, *Strombosia scheffleri* and *Zanthoxylum* spp. can be found. And finally, within the higher altitude upper montane forest - in areas that are edaphically drier - common taxa include *Faurea saligna*, *Hagenia abyssinica*, *Nuxia congesta*, *Olea capensis* ssp. and *Podocarpus milanjianus*. It is also worth noting that these are not fixed altitudinal lists, as taxa that are usually associated with dry environments in high altitude areas can also be present at lower altitudes, but in wetter locations (Marchant and Taylor, 2000). For example, *Podocarpus milanjianus*, is present on the north-west side of Lake Victoria at 1200 m, but it is a species usually found in a dry upper montane environment (Lind et al., 1974). Within a number of mountainous areas (e.g. Mount Elgon, the Aberdares and the Rukiga Highlands) bamboo-dominated (*Sinarundinaria* spp.) forest can also be found. The

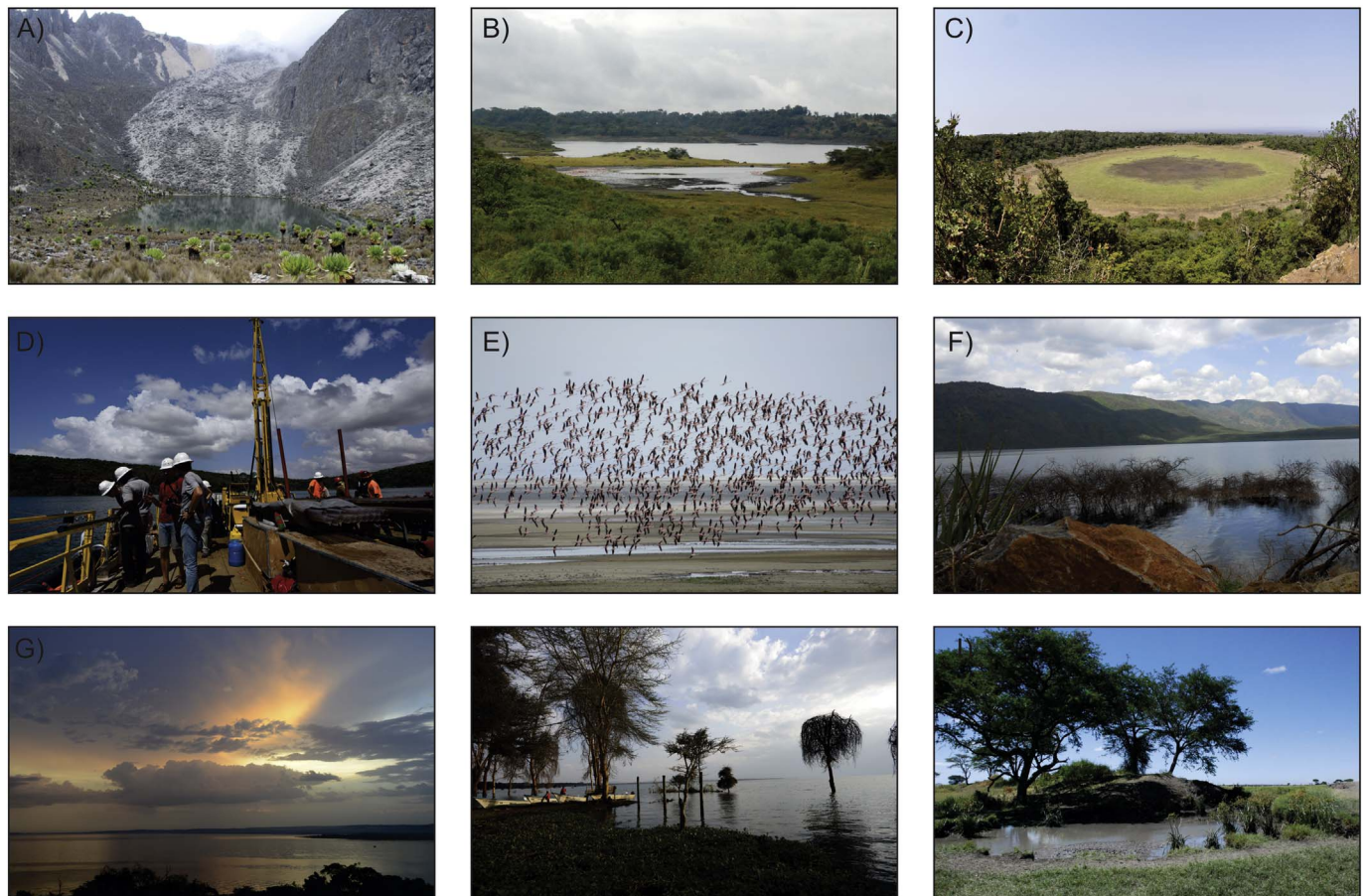


Fig. 7. Sources of palaeoenvironmental geoarchives. A) Oblong Tarn, Hausberg Valley, Mount Kenya (photo: Hilde Eggermont). B) Mommella Lakes atop pyroclastic ejecta from Mount Meru, Arusha National Park, Tanzania (photo: Colin Courtney-Mustaphi). C) Paradise Lake, an extinct volcanic crater on Mount Marsabit (photo: Rob Marchant). D) Core drilling machinery to collect the long sediment stratigraphy from crater Lake Challa (photo: Rob Marchant). E) Lake Manyara, a rift valley lake in northern Tanzania (photo: Rob Marchant). F) A view of Lake Bogoria from the west shore facing southeast showing submerged vegetation from rapid lake level increases (photo: Colin Courtney-Mustaphi). G) Lake Victoria (photo: Rob Marchant). H) Lake Naivasha shore line (photo: Rob Marchant). I) An abandoned dam constructed by agriculturalist German colonial settlers near Nyasiror ranger station, Grumeti Game Reserve, northwestern Tanzania (photo: Colin Courtney-Mustaphi).

Arundinoid grass *Arundinaria alpina* dominates the bamboo ‘zone’ where it can form mono-specific stands. Within East Africa bamboo is not thought to be a distinct vegetation type in its own right, but is rather considered to represent a successional stage within montane forest (Hemp, 2005a, 2005b, 2006; Marchant and Taylor, 2000). This interpretation is further supported by the co-occurrence of taxa indicative of the regeneration of lower montane forest within bamboo stands (Marchant and Taylor, 2000). The upper altitudinal limit of the upper montane forest varies from place to place, and reaches up to 4000 m asl along stream courses on Mount Kenya (Coe, 1967) and can be as low as 2300 m asl on the Eastern Arc Mountains of Tanzania (Lovett and Pócs, 1993).

In the lower parts of the ericaceous belt (3300 to 2700 m), which can experience nightly conditions of frost, overheating and physiological drought during the day, montane forest taxa can be present (Fig. 6C). More regular rainfall, or occult precipitation, can encourage tree growth at higher altitudes, as can be seen in topographically protected, humid valley slopes (Coetzee, 1967; Coe, 1967). Therefore, the floristic composition of the lower part of the belt is very sensitive to the local climatic regime. Ericaceous belt vegetation is characterised by a microphyllous, thorny habit; other xeromorphic features are common (Fig. 6B). Three main communities are recognised (Hedberg, 1954). Subalpine arborescent ericaceous and *Senecio* forest (Fig. 7A foreground) is dominated by *Agauria salicifolia*, *Artemisia afra*, *Cliffortia nitidula*, *Erica arborea*, *E. ruwenzoriensis*, *Hypericum* spp., *Philippia johnstonii*, *P. keniensis* and *Stoebe kilimandscharica*. Subalpine ericaceous and

mixed shrub communities are dominated by species of *Alchemilla* and *Helichrysum*. There is relatively close floristic similarity between the composition of ericaceous belt vegetation on different mountains of East Africa; the following genera being common; *Alchemilla*, *Artemisia*, *Cliffortia*, *Deschampsia*, *Helichrysum*, *Hypericum*, *Philippia* and *Stoebe* (Hedberg, 1951; Hemp, 2006). Although having relatively poor species diversity, the Afroalpine flora (> 3800 m) is sufficiently distinct from the surrounding lower floras to warrant its own zonation (Hedberg, 1964). No < 80% of the taxa are endemic to the high mountains of East Africa, indicating that as a vegetation type it has long been isolated from other African mountains and more temperate areas (Hedberg, 1964). *Alchemilla* spp., *Helichrysum* scrub and *Senecio* spp. are the dominant taxa in this zone (Hedberg, 1951; Hamilton, 1969), and other genera present include *Carduus*, *Festuca* and *Lobelia*. As one moves into the lower altitudes, Afroalpine vegetation intergrades with microphyllous thicket (Hedberg, 1964). Within this *Philippia* and more rarely *Erica* dominate. These can form dense forest or open scrub depending on local edaphic and climatic factors (Harmsen et al., 1991). Above the Afroalpine vegetation is a nival zone, this is defined by the sparse vegetation cover and rocky barren areas that characterise the Afro-montane deserts of the highest peaks (Figs. 6A, 7A and 8A) of Kilimanjaro, Mount Kenya, the Virunga Range and Ruwenzori Mountains.

2.5. Disturbance factors influencing ecosystem composition

The preceding description is based on the species distributions that

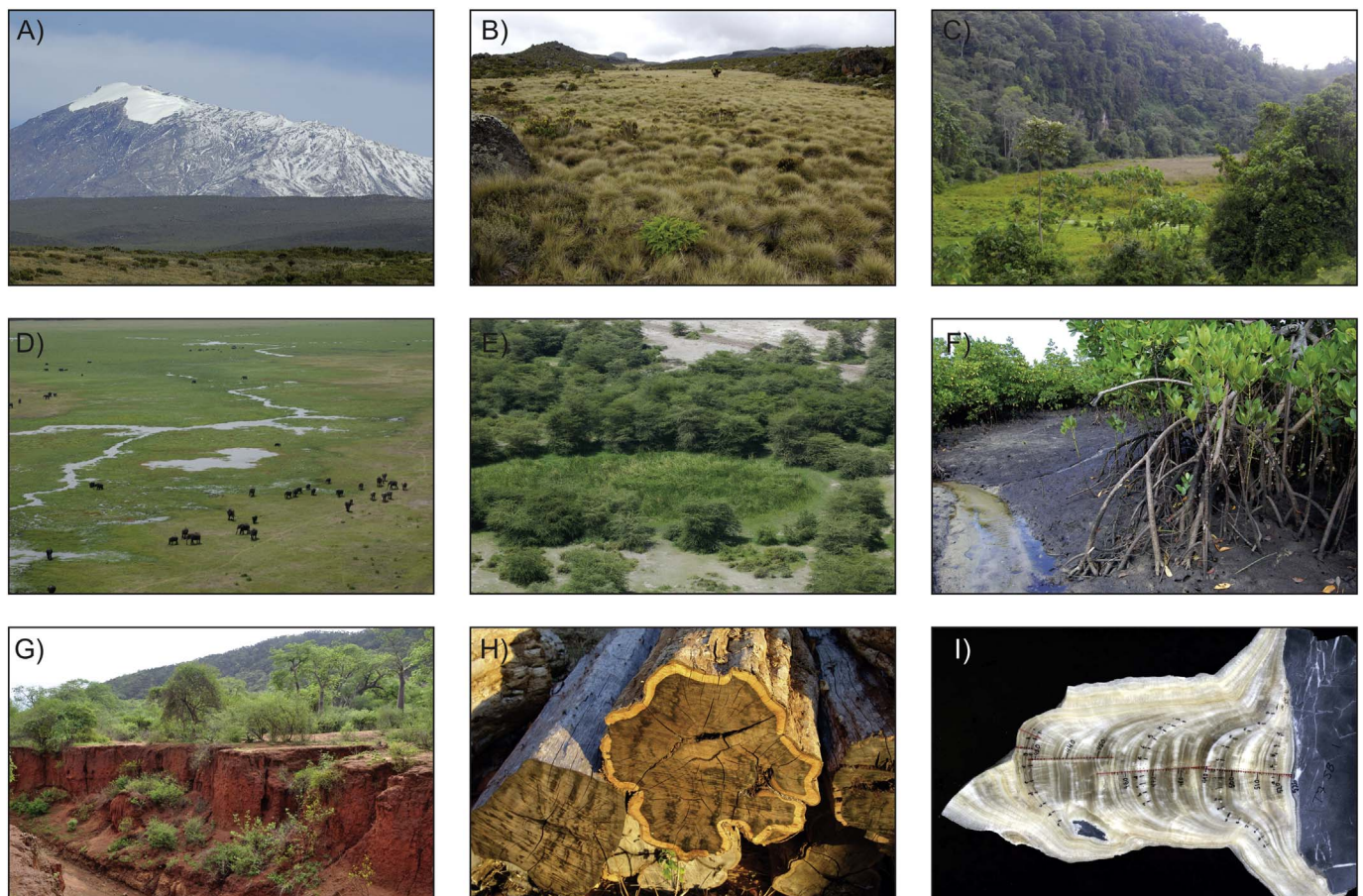


Fig. 8. Additional sources of palaeoenvironmental information. A) Glaciers and multi-annual ice on Kilimanjaro (photo: Rob Marchant). B) Maua mire, at nearly 4000 m asl, containing 3000 years of sediment accumulation, south-eastern Kilimanjaro (photo: Rob Marchant). C) At over 2100 m asl, Rumuiku Swamp sits within a volcanic crater on eastern Mount Kenya (photo: Colin Courtney-Mustaphi). D) Palustrine swamp, a source of organic-rich sediments in the relatively flat areas of Amboseli National Park (photo: Rob Marchant). E) Cyperaceae dominated wetland northern Kenya (photo: Rob Marchant). F) Mangrove sediments, Zanzibar (photo: Rob Marchant). G) Fluvially incised dry riverbed and exposed soil facies northern Tanzania close to Himo (photo: Rob Marchant). H) Cut timbers at Mpingo showing tropical tree growth rings (photo: Neil Burgess). I) A cave deposit used for palaeoclimatic investigations, this example was collected from Cold Air Cave, South Africa (photo: Karin Holmgren).

occur when climate is the determining factor. Superimposed on this dominant control are local disturbance influences such as fire, agricultural expansion and grazing regimes, all of which express themselves in the composition and distribution of vegetation. Given the long-term record of human inhabitation in East Africa, it is not unexpected that there has been extensive clearance and/or modification of the natural vegetation. Disturbance regimes span from total conversion natural vegetation to intensive agriculture and pasture, through to mixed agroforestry and seasonally exploited migratory rangelands. Much of the deforestation has focused on the mid-altitudes and very little primary montane forest remains between 1500 and 2500 m (Goudie, 1996). Montane forest vegetation is now largely restricted to protected areas such as Bwindi-Impenetrable Forest, Mount Elgon, Udzungwa and the Virunga Volcanoes National Parks; most of the remaining montane vegetation has been modified to varying degrees by people. The resultant vegetation often has components indicative of disturbance, such as ruderal species of *Chenopodium*, *Dodonaea*, *Plantago*, *Rumex* and *Vernonia*. Tree genera also indicative of disturbance can be locally more common; such as species of *Alchornea*, *Croton*, *Dombeya*, *Erythrina*, *Hagenia*, *Harungana*, *Macaranga* and *Polyscias*. However, care must be taken when translating the presence of these taxa as disturbance indicators, as they can all occur naturally within montane vegetation, albeit at relatively low values.

Fire is an important ecological driver at the forest-savannah ecotone, promoting open grassland ecosystems at the expense of forest (e.g., Cochrane et al., 1999; Bond and Keeley, 2005). Fire can even maintain a grass-dominated ecosystem in regions where the environmental (precipitation) regime would be expected to support forest (i.e., ‘unstable savannah’, Sankaran et al., 2005). Satellite and long-term field data have shown that fires in areas of grass-dominated savannah are controlled principally by the availability of fuel (Bond and Keeley, 2005). Although somewhat counter-intuitively, wetter conditions allow the production and accumulation of herbaceous litter, which means there is more fuel available for the fires; in contrast, drier conditions have the reverse effect as the production of herbaceous litter is more limited (Archibald et al., 2010). Over large areas of East Africa, the observed spatial and inter-annual variability in biomass burning is primarily controlled by precipitation (relative drought) and land use (deliberate ignition, landscape fragmentation) (Carcaillet et al., 2002; Archibald and Roy, 2009; Colombaroli et al., 2014). East African ecosystems appear to have experienced highly variable responses depending on the type of land use (pastoralism or farming) and the ecosystem involved (e.g., dry grassland versus wet savannah woodland). In climates that support rain-fed agriculture (e.g., large areas of western Uganda) intensive human impact associated with high demographic pressure has often resulted in passive fire suppression, due to landscape fragmentation from the establishment of the modern cultural landscape consisting almost entirely of cropland under near-continuous rotation (Andela and Van Der Werf, 2014). In the drier climates characterizing much of Kenya and eastern Tanzania, a combination of pastoralism and dispersed subsistence agriculture instead results in more frequent and extensive burning, to either clear marginal farming land or to promote the nutritional quality of grazing pastures (Laris, 2002; Laris and Wardell, 2006).

The impact of herbivory on primary production is explained by grazing optimization theory (Georgiadis et al., 1989), whereby herbivores promote or suppress tree cover depending on their size, density and mobility. For example, small browsers have been shown to suppress shrubs and large browsers can alter the structure and density of woodlands (Bond and Keeley, 2005; Bond, 2008; Midgley and Bond, 2015; Hempson et al., 2015). Moreover, elephants and humans are keystone species in regulating savannah patch dynamics (Western and Maitumo, 2004). Large and mobile herbivore populations, particularly African savannah elephants (*Loxodonta africana*), can destroy tree cover, causing the loss of habitat for browsing species (Guldmond and Van Aarde, 2008), and can modify tree species composition

(Rugemalila et al., 2016). Whilst mature savannah trees are probably relatively unresponsive to these impacts, in that they are able to withstand prolonged droughts and grazing, juvenile specimens will be more acutely affected.

3. Reviewing evidence for environmental and cultural change in East Africa

East Africa has long been a locus of cultural and socio-economic changes and a major conduit and contact zone between diverse food-producing traditions. The region is characterized by a diverse range of land uses in a relatively small area because of the diversity in the physical environment, as described above. Throughout the year, the alternating dry and wet seasons also provide ideal growing and planting seasons on nutrient-rich volcanic soils. The different forms of evidence for documenting change over the past 6000 years across the East African landscape will be presented in four time slices of 1500 years. These time slices correspond to broadly different environmental regimes: the global mid-Holocene Climate Optimum around 6000 yr BP, the extensive drought centred around 4000 yr BP at the termination of the African Humid Period, the subsequent relatively mesic period from around 3500–2500 yr BP, followed by the last 2500 years characterised by alternate dry and wet phases. The review will initially focus on the environmental evidence and then on human history.

3.1. Evidence for environmental change across East Africa

Multiple streams of evidence are available to document past environmental change in East Africa; each with different constraints and limitations to inform our understanding of palaeoenvironments. Palaeoenvironmental research makes use of geoarchives and other natural sources of information on the Earth's history to examine signals of environmental variability, often through the use of environmental indicators and proxy measurements (Last and Smol, 2001; Smol et al., 2001a, 2001b).

In East Africa, the most numerous records of past environmental variability have been established from the analysis of lacustrine, palustrine and peat geoarchives (Figs. 7 and 8). As sediments accumulate in these terrestrial depositional systems, the properties of the sediment stratigraphy maintain environmental signals that provide a history of ecosystem variables, such as precipitation, biological productivity, and vegetation type (Romans et al., 2016). Variability in these environmental signals can be caused by natural and anthropogenically modified processes; thus, they provide us with insights into long-term environmental processes, abrupt ecosystem perturbations and associated consequences, and human–environment interactions. Other sources of palaeoenvironmental information include coastal deposits, Indian Ocean marine sediments, corals, cave deposits, and tree rings (Stahle et al., 2009). The environmental signals embedded within these geo- and bio-archives provide us with information on how ecosystem processes varied at multiple spatial and temporal scales and these resolutions are dependent on the different sources of palaeoenvironmental information, the degree to which the signal is captured by the system, and sampling intensities employed during analysis.

3.1i. Geoarchives and palaeoenvironmental change

There are multiple sources for examining the geological and environmental history of East Africa for the past 6000 years. The East African landscape is characterised by numerous lakes of variable size (Fig. 7), and many swamps, mires and peatlands (Fig. 8). The large basins are influenced by broad-scale regional processes, such as climate and climate-mediated erosion rates, and the sediment bases are often much older extending beyond the Quaternary (Butzer et al., 1972; Johnson et al., 2002). The smaller, shallow, lakes of the Western Rift respond more rapidly to hydroclimatic changes and can therefore dry out completely, often leading to discontinuous late-Holocene sediment

records (Fig. 7E and H) (Verschuren et al., 2002). Small lake basins are often much younger than their larger counterparts, forming at the end of volcanic processes or within low depressions in the landscape. These can provide sediment records from the Pleistocene or earlier (Fig. 7B and C) (Ficken et al., 2002; Rucina et al., 2009; Courtney-Mustaphi et al., 2016; Maslin, 2016). Each lake can have multiple high and low stands as the hydrological budget changes (Nash et al., 2016). These systems are often influenced by a combination of broad-scale climatic, as well as local-scale, factors. An important mechanism of the formation at sedimentary archives at the highest elevations is the retreat of the montane ice caps since the Last Glacial Maximum, which led to the development of small lakes and mires in deglaciated valleys. It is the sediments from these features that provide Holocene environmental information (Fig. 7A) (Perrott, 1982; Rietti-Shati et al., 1998; Karlén et al., 1999; Courtney-Mustaphi et al., 2017).

Other sources of palaeoenvironmental history for East Africa come from coastal mangroves (Fig. 8F), corals, glacial deposits (Fig. 7A background and 8A), geomorphology, dendrochronology (Fig. 8H), speleothems (Fig. 8I), soils (Fig. 8G), and marine sediments. Mires, peat deposits and swamp (palustrine) deposits provide another source of sedimentary palaeoenvironmental records that extend from the Pleistocene in mesic regions (Fig. 8C) and from the late Holocene in semi-arid areas (Fig. 8D and E). Swamp deposits can also be sensitive to drying and subsequent breaks in sediment accumulation, bioturbation from plant-root growth, and large animals may disturb the temporal sequence of the stratigraphy.

The number of published sediment-based records for past environmental change from East Africa (e.g., Karlén et al., 1999) is steadily increasing. A long tradition of palaeoecological research, extending to some of the pioneering work of Livingstone, Coetzee, Morrison and Van Zinderen Bakker since the late 1950s and early 1960s, has established an increasingly dense assemblage of palaeoecological archives that clearly demonstrate the highly responsive nature of East African ecosystems to past climatic variability (Finch et al., 2014). Recent advances in database development and repositories for palaeoenvironmental datasets have begun to build the foundation for large-scale analyses to examine spatiotemporal patterns in ecosystem change and human–environment interactions (Vincens et al., 2007a; Goring et al., 2015; Courtney-Mustaphi and Marchant, 2016). These are facilitating a move away from the largely descriptive phase of environmental histories.

3.1ii. Detection of cultural changes in East African gearchives

From the early Holocene through until the present day, human-induced vegetation change has gone from being relatively minor and restricted to a few locations, to becoming a widespread and dominating force across even remote and inhospitable environments (Hamilton, 1982). Increasing human pressure on natural resources - radiating out from urban centers - has also accelerated vegetation change more recently. Detecting anthropogenic signals and diagnostic characteristics in palaeoenvironmental data can be achieved through examining sedimentologic measurements (e.g., sediment magnetism, particle sizes, isotopes) and proxy indicators (e.g., pollen types, plankton and mollusc remains) associated with known types of human land-use or land-cover change consequences and temporal associations with archaeological or documentary evidence. Testing hypotheses regarding land-cover change within a modelling framework offers additional ways to query palaeoenvironmental evidence. Bringing each of these approaches together enables a holistic examination of anthropogenic modification of the environment and can be used to partition the degree of change exerted by human activities.

The principal anthropogenic influences on the landscapes of East Africa over the Holocene are a reduction in arboreal cover and changes in fire activity. These interpretations of anthropogenic change are inferred from the pollen record (a reduction in arboreal pollen) and other proxies, such as peaks in microscopic charcoal (indicative of burning).

This is exemplified from numerous locations such as at Ahakgyezi (Hamilton et al., 1986; Taylor, 1990) and Muchoya Swamps (Taylor, 1990; Marchant and Taylor, 1998) in Uganda, Sacred Lake (Street-Perrott et al., 1997) in Kenya, and Lake Tanganyika (Cohen et al., 1997; Msaky et al., 2005) and Lake Masoko (Vincens et al., 2007b) in Tanzania (for locations see Fig. 1). Similar changes in the composition of vegetation and modified burning regimes are also evident in mid-elevation records from Mount Shengena, in the Eastern Arc Mountains (Finch et al., 2017). These indicators are generally interpreted to be associated with human land use and intensification of human activities (Finch et al., 2017), rather than the mere presence of people in the landscape.

Of course, such simplistic interpretations are often challenged when there are multiple drivers interacting (Salzmann et al., 2002; Marlon et al., 2013, 2016; Heckmann et al., 2014). Analysis of some palaeoecological archives from African contexts has led to the interpretation that a reduction in pollen abundance from forest tree taxa is accompanied by an increase in grass pollen and is associated with clearance (e.g., Vincens et al., 2007a). This could be indicative of a preference for agroforestry trees (e.g., *Arundinaria alpina*), the presence of cultivated crops (e.g.; castorbean *Ricinus communis*), and/or disturbance, shown through the presence of pollen from ruderal plants indicating clearance for agriculture or pastoral activities. Poaceae pollen grains $> 80 \mu\text{m}$ are assumed (*a priori*) to represent the non-native crop maize (Eubanks, 1997), while grains $60\text{--}80 \mu\text{m}$ fall in the cereal category, but cannot be attributed with certainty to maize (Tsukada and Rowley, 1964; Fearn and Liu, 1995). They are hence attributed to indigenous cereals such as finger millet (*Eleusine coracana*) and/or sorghum (*Sorghum bicolor*). Poaceae pollen grains $< 60 \mu\text{m}$ are counted as wild grasses as they cannot be attributed to cereals. It is not possible to positively identify pollen from most cultivated plants in the palaeoecological record with light microscopy alone (cf. Msaky et al., 2005), which makes detailed studies of land use from pollen alone unachievable at present. This is exemplified at the archaeological site of Munsu, where it proved to be impossible to distinguish between sorghum and millet from wild grasses - both in the preserved pollen assemblage and in the phytoliths. However, maize can be identified from phytoliths (Leju et al., 2006; Leju, 2009), and these samples are thought to postdate 170 yr BP.

From the mid-Holocene onwards it is not always possible distinguish between a climatic or anthropogenic signal in the palaeoenvironmental record. This equifinality is best demonstrated with an example. High levels, or peaks, in microscopic charcoal often occur with high percentages of grass pollen. In the section above it has been suggested that this can be an indication of land use, however, it can also be considered as a drought event (cf. Marchant and Hooghiemstra, 2001). In certain situations, particularly in swamps and peatlands where the pollen signal is likely to be relatively local (compared to lakes), dung fungal spores can be used to aid in differentiating between a human or climatic cause for the environmental signature present. Certain fungal spores, and assemblages of them, can be indicative of human activity e.g. settlement sites, as well as the presence of grazing herbivores. Importantly, these fungal assemblages differ from those of undisturbed natural ecosystems (van Geel et al., 2011). Thus far, there has been limited use of fossil fungal spores in palaeoenvironmental studies in East Africa, the main exceptions to this have been work carried out in the vicinity of the archaeological site of Munsu in Uganda (Leju et al., 2006; Leju, 2009), and recent work in coastal Kenya (Szymanski, 2017).

Fire regimes represent one area where human–environment interactions are deeply entangled. Even before the development of farming, humans used fire as a tool for manipulating the landscapes they inhabited. Patterns of landscape-scale fire use vary according to land-use regime; this variability means that humans have influenced different components of fire regimes in varying degrees of importance through time (Archibald et al., 2012). Details matter: the timing, frequency, and scale of burning all structure ecological impact and complicate our

understanding of the effects of anthropogenic burning on biodiversity and vegetation structure (Brockett et al., 2001; Parr and Andersen, 2006; Gil-Romera et al., 2011; Donaldson et al., 2018). These important ecological outcomes may be difficult to differentiate in palaeoenvironmental records and require testing in modelling and field-experiment frameworks (Marlon et al., 2016; Hawthorne et al., 2017).

3.1.iii. Chronological and methodological considerations

A point where it should be possible to link archaeological and palaeoenvironmental records is through chronology, as both types of sites have often been dated using radiocarbon dating. However, comparison and correlation between sites is complex (Blaauw et al., 2007; Parnell et al., 2008; Gearey et al., 2009), and proves challenging at the moment for a number of reasons, the first of which is the accuracy of sample selection. Chronologies are only as good as the association between the material being dated and the event of interest (Bird et al., 2005). Within palaeoecology most work has been undertaken at lake sites where there is in an absence of short-lived, single-entity plant macrofossils, which means that bulk sediment samples are often dated instead. This is potentially problematic, as the processes of sediment accumulation and erosion need to be fully understood for the dates to be meaningful. Also, the sediments may be subject to the ‘old-carbon effect’, returning determinations that are considerably older than the event in question.

Within archaeology, sampling issues pose similar challenges, and in older literature it is often unclear as to whether samples were taken from secure contexts, which again raises the question of provenance – is the event in question actually being dated? In addition, unidentified charcoal was frequently dated, which raises the question of the ‘old wood effect’, especially within the savannah landscapes of East Africa

where acacias dominate, as these trees can potentially live for many hundreds of years.

Secondly, there is the issue of the precision of the dates. Rarely is it possible to obtain dates from conventional radiocarbon determinations that calibrate to a decadal scale (Blaauw et al., 2011; Stanley et al., 2003). The fluctuating nature of the radiocarbon calibration curve also means that plateaux exist, and these can produce calibrated dates that span hundreds of years (Reimer et al., 2004, 2013). The period of 350–50 yr BP is one such period that can prove problematic for the dating of sites in East Africa, especially those associated with historic agriculture, the introduction of imported crops and the caravan trade.

However, once issues of accuracy and precision are acknowledged then they can start to be addressed. This is through careful sample selection, combining multiple dating methods and using other stratigraphic information to constrain the calibrated date using Bayesian statistical techniques (Bayliss, 2009). The best palaeoenvironmental example from East Africa where this has occurred is the high-resolution record from Lake Challa on the Kenyan/Tanzanian border (Blaauw et al., 2011). Here, not only were radiocarbon determinations obtained on 168 bulk sediment samples, but also these samples were paired with radiocarbon analyses on terrestrial material or ^{210}Pb -derived determinations to test for any old carbon offsets. The calibrated dates were then constrained using Bayesian statistics to produce age estimates for the Holocene that ranged from approximately 50–230 yr (Blaauw et al., 2011). Whilst all palaeoenvironmental age-depth models are informed ‘best estimates’ of the chronology of the sediment being studied (Telford et al., 2004; Heegaard et al., 2005; Parnell et al., 2011; Trachsel and Telford, 2017) and contain inherent uncertainties and temporal aggregations (Blaauw and Heegaard, 2012), the Lake Challa

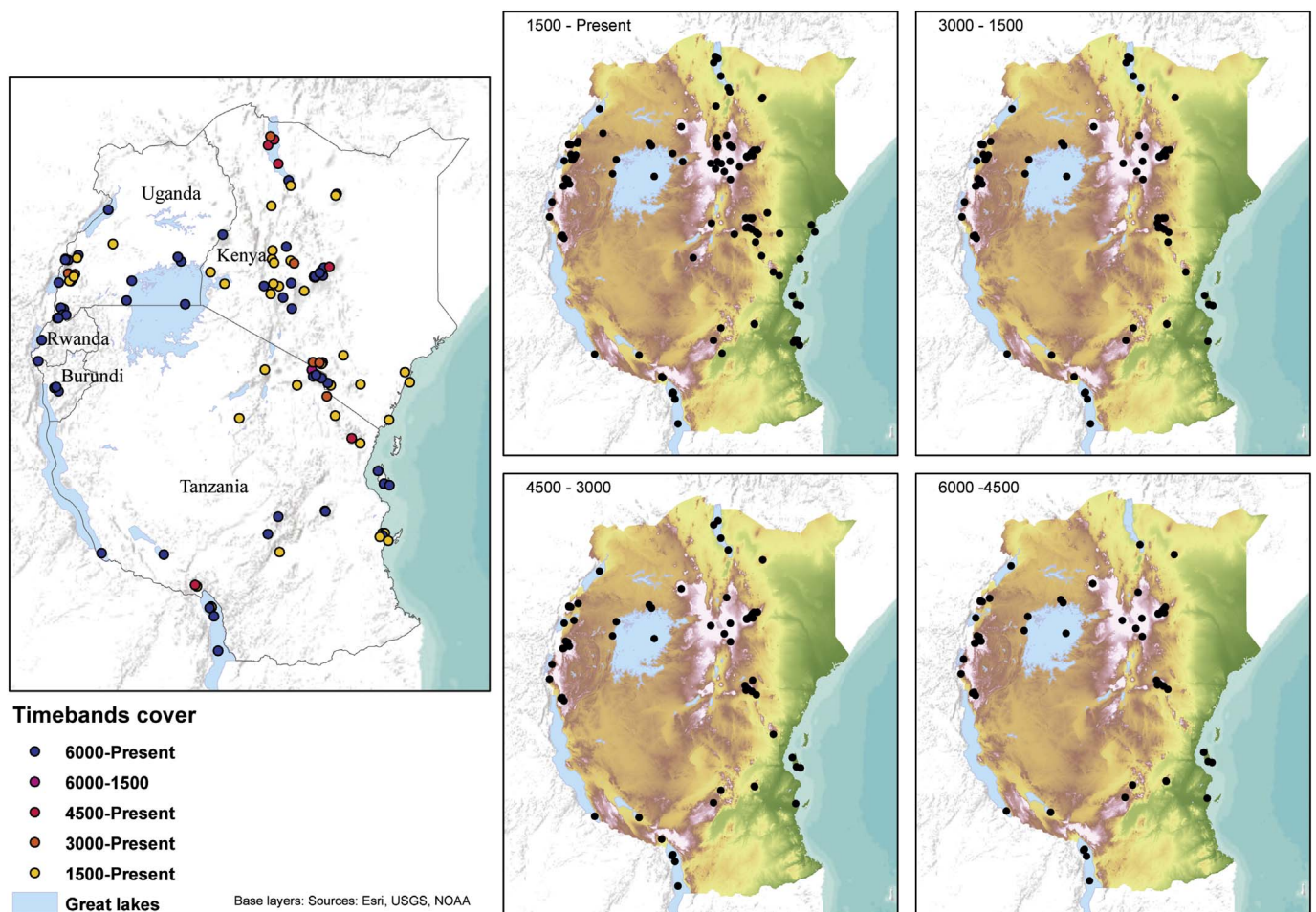


Fig. 9. Plots of palaeoenvironmental sites and modern elevation (SRTM-250 m) by time period.

example demonstrates that it is possible to provide a much more precise chronology when multiple methods and techniques are applied to carefully selected samples. Furthermore, compiling palaeoenvironmental data requires careful analyses of the geochronological information to catalogue and maintain transparency for age-depth model uncertainties (Giesecke et al., 2014; Flantua et al., 2016).

Archaeologically, the use of Bayesian statistics to constrain calibrated radiocarbon dates is also starting to be used. This is clearly seen in the work in of Crowther et al. (2016b) examining the introduction of Southeast Asian crops to East Africa. In this study, which considered 18 sites from the East African mainland coast, nearshore islands (e.g. Pemba, Zanzibar), the Comoros and Madagascar, 48 macrobotanical samples (charred seeds) were selected for dating, chosen to avoid long-lived species. The resulting dates were subsequently modelled using Bayesian statistics to take into account the stratigraphic relationships between samples, and hence to produce a narrower estimated date range for when the crop introductions occurred.

This review brings together dating information from archaeological and palaeoenvironmental sites in East Africa, in particular, bibliographic site information contained in the SM1–3. It remains a future project to recalibrate and re-interpret the currently available dates. Authors have reported geochronological information in various styles, meaning that new analysts need to compile information from multiple sources and not all details concerning geochronologies and age-depth models are explicitly reported. For example, metadata concerning radiocarbon samples, the variety of laboratory reporting styles (raw data, or normalisation techniques to account for variation in the production of atmospheric radiocarbon), the calibration curves used

(Reimer et al., 2013; Hogg et al., 2013; Crowther et al., 2016b), mean that the original publications should be consulted for any queries concerning dating (Millard, 2014). Compiling geochronologies and age-depth models requires a sophisticated framework (Flantua et al., 2016) for transparency and open-access to underlying data for repeatability and reproducibility (Courtney-Mustaphi and Marchant, 2016; Wright, 2017a, 2017b).

3.2. Environmental history from geoarchives

Our review identified 129 published and unpublished palaeoenvironmental records within East Africa, which are mapped on Fig. 9 and presented in Table SM1. The palaeoenvironmental sites are also mapped on the present-day physiographic landscape (Fig. 10) and climate space (Fig. 11) of East Africa. A total of 66 sites spanned the entire 6000 year time period or longer, 75 sites covered 4500–3000 yr BP, 85 records covered 3000–1500 yr BP, and 128 covered 1500 yr BP–present (Fig. 9). Geochronological controls varied based on the type of geoarchive, but were dominated by radiometric dating ($n = 116$ sites), with eight sites making use of incremental dating (coral and dendrochronology), three sites using temporal matching (palynostratigraphy or stratigraphy), and two sites using repeat imagery of the past few decades. Sections 3.2i to 3.2iv below provide descriptions and interpretation of the environmental changes by 1500 year time periods from 6000 years BP to present.

3.2i. Environmental history 6000 to 4500 yr BP

Our review starts at 6000 yr BP, which is towards the later phase of

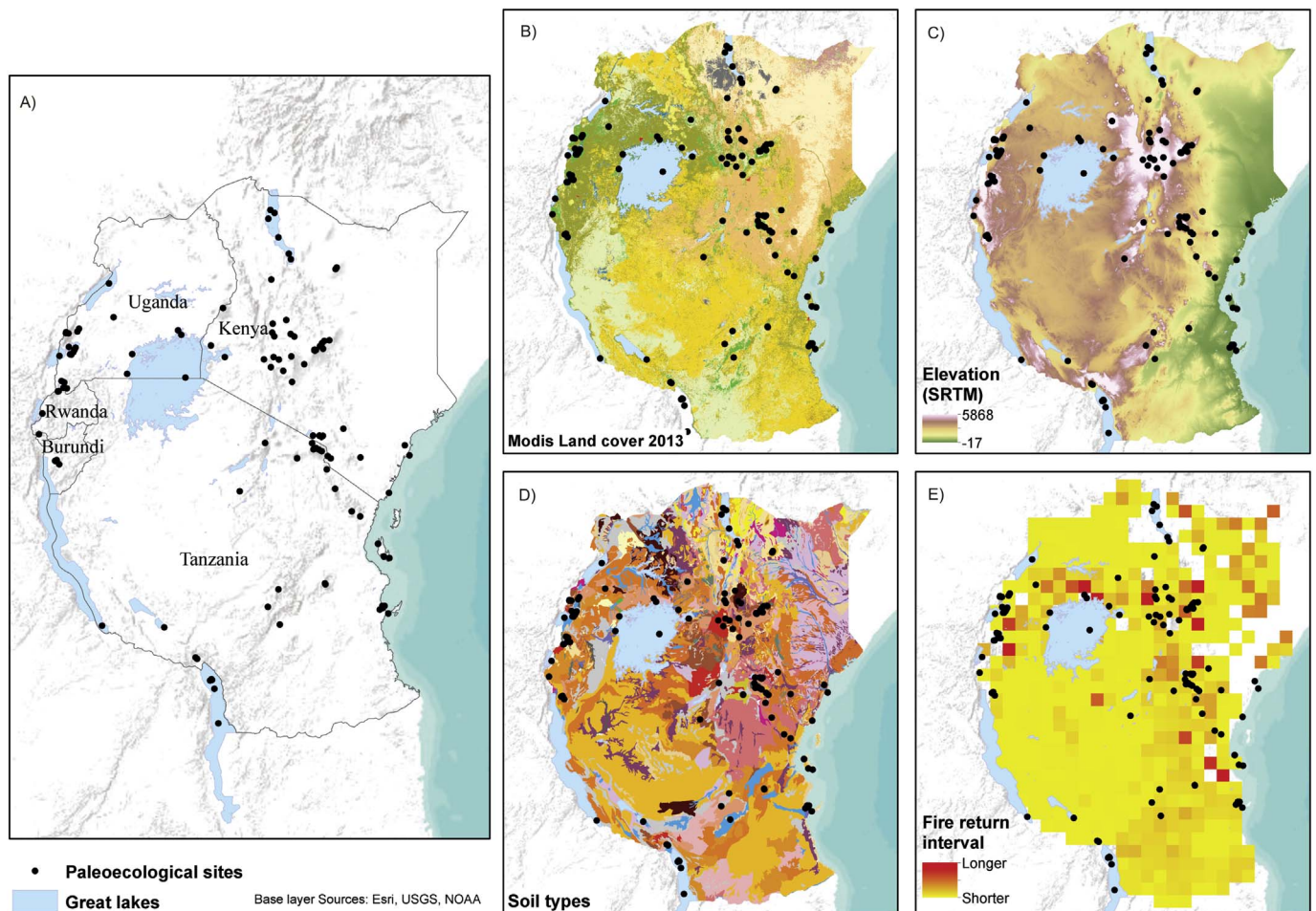


Fig. 10. A) Plot of palaeoenvironmental sites and elevation, B) vegetation as MODIS land cover classes (2013), C) elevation (SRTM-250 m), D) soil (Soil Atlas of Africa), and E) fire return interval. Map legends are presented in Figs. 2 and 4 and references in the captions for those figures.

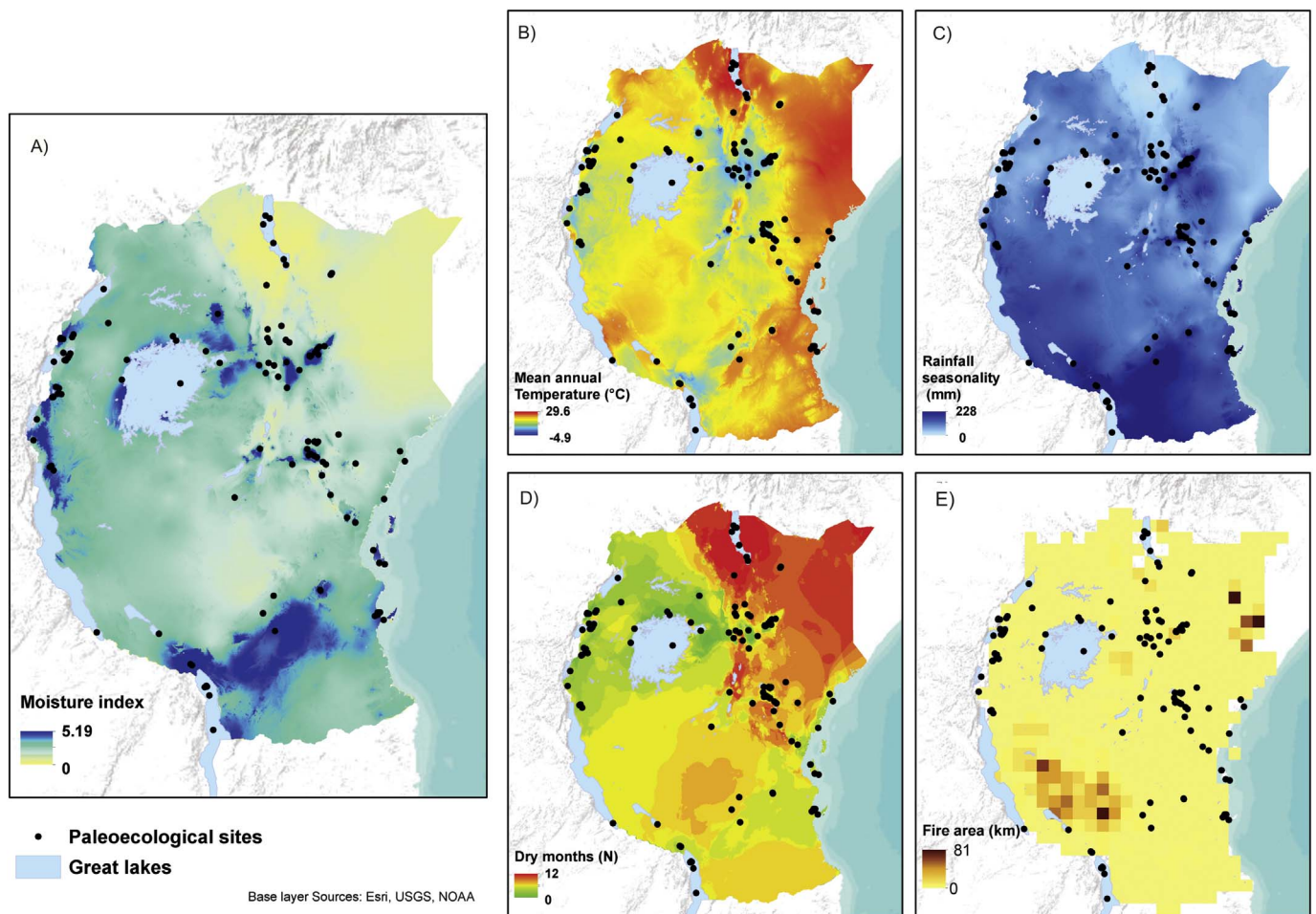


Fig. 11. Palaeoenvironmental sites distributed over maps of: A) moisture index, B) mean annual temperature, C) rainfall seasonality, D) number of dry months per year (Africlim 3.0), and E) burned area (MODIS active fire product MCS14ML from April 2000 to June 2015 Archibald et al., 2010; Hempson et al., 2017). Map legends and references are presented in Fig. 3 and caption.

the globally evident Holocene climatic ‘optimum’ and end of the African Humid Period (Shanahan et al., 2015). Climate in East Africa was generally slightly warmer and wetter than present with most ecosystems experiencing minimal and diffuse anthropogenic impacts (Bonnefille and Riollet, 1988). The mid-Holocene (8200–4200 yr BP; Walker et al., 2012) is characterised by climatic variability driven by natural processes and intensifying anthropogenic modifications towards the end of this period (Stott et al., 2000; Kaplan et al., 2011; Ruddiman et al., 2011, 2015). In eastern Africa, the moist forest biome followed a similar distribution to the present (Jolly et al., 1998b). Some palaeoecological records from East Africa suggest that aridity increased from the early Holocene as temperatures rose; Barker et al. (2011) propose that annual temperatures were around 2–3 °C higher in the Holocene compared to the Last Glacial Maximum (21,000 yr BP). This increase in arid conditions can be seen in a pollen record from Lake Tanganyika, which shows a change in the catchment area of the lake from being forested to becoming drier and more open grassland from 5000 yr BP (Msaky et al., 2005). Using paired compound-specific isotope records, Tierney et al. (2010) also illustrate that a major change in vegetation occurred around Lake Tanganyika at 6200–5500 yr BP. Other records exist in East Africa that also suggest that a change in aridity occurred in the mid-Holocene. An example of this can be seen in lake level changes at Lake Turkana in northwestern Kenya, where the lake level is thought to have decreased in the form of a complex sequence of variable stages between ca. 8000 and 4500 yr BP, ultimately resulting in a regression of 90 m between 5200 and 4500 yr BP (Bloszies et al., 2015). Whilst it continued to maintain this lowered level for much of the mid- to late

Holocene, there is considerable variation in the magnitude of this reconstructed change due to the application of different proxies and dating controls (Owen et al., 1982; Garcin et al., 2012; Morrissey and Scholz, 2014; Bloszies et al., 2015). In another example, the diatom record from Lake Victoria (Nakintu and Lejju, 2016) indicates a phase of low precipitation, but moderate lake levels, between c. 5000–4000 yr BP. The high abundance of *Aulacoseira granulata* and *A. ambigua*, indicates well-mixed (moderately deep) water, but low abundance of all diatoms and the presence of Cyperaceae phytoliths suggest low rainfall.

Detailed characterisation of this period is challenging as many sites throughout East Africa are characterized by sedimentary gaps or temporal hiatuses around this time, and their scientific contribution can be overlooked. Problematic sediment archives are often perceived as negative results, undermined by reviewers and editors, and frequently remain unpublished; but these are crucial for examining histories and widescale patterns, particularly of semi-arid ecosystems. Gaps in sedimentation are often regarded as a lack of information that should be simply delimited and negated, although it could be argued that the presence of sedimentary gaps are one of the strongest palaeoenvironmental indicators within a sedimentary sequence, as it potentially indicates how the sedimentary basin responded to local environmental changes. The main problem in defining sedimentary gaps is determining whether they result from a lack of sediment accumulation or from post-depositional erosion of the sediment. In the case of Mubwindi Swamp, the gaps are thought to result from erosion, particularly as sediment erosion can be observed at present within the southern part of Mubwindi Swamp (Marchant et al., 1997; Marchant and Taylor, 2000).

The temporal occurrences of the hiatuses in the Mubwindi Swamp sequence reiterate this suggestion as they occur during periods of increased effective moisture throughout the region (Bonnefille, 1987), thus providing the mechanism through an increased hydrological budget necessary to erode *in situ* sediments. Due to the long gaps in sedimentation at some of the sites, often much of the material laid down during the Holocene is missing. Equally, reinitiation of peat accumulation during the late Holocene (around 4000 yr BP) may have commenced as a consequence of gradual aridification or increased seasonality (Section 3.2ii). Throughout western East Africa, there appears to be a slow, but sustained increase in the depth of sediment accumulated down the altitudinal sequence: no peat formed at the higher Kuwasenkoko Swamp, Rwanda (Hamilton, 1982) at 2340 m asl, or at Muchoya Swamp, Uganda, at 2260 m asl (Jolly et al., 1997), but an accumulation of 7–10 m of peat was recorded at Ahakagyezi Swamp, Uganda (Taylor, 1990) at the slightly lower elevation of 1830 m asl. This variation in the presence/absence of peat is thought to be common throughout central Africa, where the rate of peat accumulation is determined by increased moisture and temperature, thus facilitating increased growth rates and/or decreased decomposition at lower altitudes. This altitudinal gradient reiterates the responsive nature of the sediment stratigraphies in isolating the forcing mechanisms responsible for environmental change in East Africa.

Interestingly, the lack of woody biomass in the present-day grassy savannahs of East Africa, not only characterises them today, but would appear from both high and low altitude palaeoecological records to have begun around 5000 to 6000 yr BP, coinciding with an increase in dry-season aridity (Barker et al., 2011; Nelson et al., 2012). The expansion of drier forest types than previously present was widespread after about 6000 yr BP, probably in response to greater seasonality (Stager and Mayewski, 1997), possibly resulting from wider increased meridional variability of the monsoon front driven by the ITCZ (Nicholson, 1994).

On the coast of East Africa, sea levels are thought to have risen dramatically following low stands of the last glacial period (Prendergast et al., 2016). Sea levels reached a mid-Holocene high stand of up to 3.5 m above present mean sea level by 4500 yr BP, followed by subsequent falls to the present level in the late Holocene (Punwong et al., 2017). Sea level change is critically important to coastal societies and it is likely that there are archaeological sites now underwater that predate the early to mid-Holocene sea level rise. Sea level variability impacts low-lying areas, such as deltas and mangrove forests (Punwong et al., 2013a), and is important to saltwater intrusion of surface and groundwater, as well as storm risk and consequences.

3.2ii. Environmental history 4500 to 3000 yr BP

This time slice is largely included within the late Holocene (from 4200 yr BP; Walker, 2012). The start of this period in East Africa is marked by a relatively abrupt event that shifted climate towards arid conditions characterised by reduced rainfall and/or a more seasonal environment (deMenocal et al., 2000). There is ample evidence for sharp lake-level drops at approximately 4000 yr BP (e.g., Gasse, 2000; Marchant and Hooghiemstra, 2004). Kiage and Liu (2006) present a summary of evidence of this abrupt shift from a number of sites around the region including the Lake Bogoria (Kenya) pollen sequence, which from 4500 yr BP shows a sharp decline in high-altitude forest pollen from taxa such as *Hagenia abyssinica*, *Hypericum*, *Stoebe* and *Ericaceae*, and increases in taxa such as *Podocarpus*, *Juniperus*, acacia and *Dodonaea*, which are more drought tolerant (Vincens, 1986). On Mount Kenya and Mount Elgon sharp increases in *Podocarpus* occurred after 4500 yr BP and 3500 yr BP, respectively (Street-Perrott and Perrott, 1988; Hamilton, 1982). These increases mark the onset and establishment of dry conditions in the region. The low abundance of Panicoid grass cuticles at Sacred Lake on Mount Kenya during the mid- to late Holocene, is also thought to indicate a shift in the seasonality of rainfall and/or fire (Wooller et al., 2000, 2003). Another record from Mount

Kenya investigating the isotopic character of the sediments from Lake Rutundu indicates a very rapid rise in C_3 grasses about 4500 yr BP that is relatively short lived (Ficken et al., 2002) and similarly may derive from a sudden change in the precipitation regime. In Rwanda and Burundi, Jolly et al. (1997) suggest that within tropical montane forests taxa that are more drought tolerant, for example *Podocarpus*, increased in abundance after 4100 yr BP.

Moving southwards, this wide-scale ecosystem response corresponds with an abrupt climate event seen in the ice core record from Kilimanjaro, Tanzania. This is represented by a visible dust layer 30 mm thick that has been interpreted as a drier phase with less vegetation cover from 4500 to 3500 yr BP on the basis of its chemical signature and the correspondence of a possible hiatus in the accumulation of the ice (Thompson et al., 2002). Lake level records from Lake Rukwa, Tanzania (Talbot and Livingstone, 1989), also indicate that a dry phase occurred at around 3000 yr BP. The outflow from Lake Kivu, Rwanda, to Lake Tanganyika (Burundi) was interrupted from about 3500 yr BP with lake levels lowered by about 75 m; this altered the salt balance in Lake Tanganyika and changed the resultant diatom flora (Haberyan and Heckey, 1987). Again, this phase of aridity can be seen in the Lake Kivu catchment, around 3200 yr BP a reduction in forest taxa occurred that coincided with an expansion of the savannah, without any indication that people were responsible for this change (Ssemmanda and Vincens, 1993). Lastly, moving out to the coast, mangrove records indicate that a lower sea level existed until approximately 3200 yr BP (Punwong et al., 2013a, 2017), which coincides with the East African dry event prior to this time. Thus, an abrupt dry event during c. 4500–3500 yr BP can be clearly identified across East Africa and beyond (Street-Perrott and Harrison, 1985; Street-Perrott and Perrott, 1988; Talbot, 1988; Elenga et al., 2000; Barker et al., 1999; Bonnefille and Chalié, 2000; Talbot and Laerdal, 2000; Marchant and Hooghiemstra, 2004; Kiage and Liu, 2006), and has been associated with a decline in the base flow of the White Nile (Talbot and Brendeland, 2001).

3.2iii. Environmental history 3000 to 1500 yr BP

Variation in the carbonate content of sediment cores from the northern part of the Lake Turkana basin, indicates several arid events occurred between c. 2200 yr BP and 1700 yr BP (Johnson et al., 1991; Halfmann et al., 1994). A lake-level reconstruction derived from Lake Tanganyika based on fossil ostracod assemblages suggests that lake levels were low from 2200 to 2000 yr BP (Alin and Cohen, 2003). Conversely, a high-resolution record of diatom-inferred conductivity (dissolved-ion content) from northern Lake Tanganyika (Stager et al., 2009) shows decreased mean water-residence time over the past 3300 years, implying higher lake levels and a general trend of climatic wetting throughout this period. In central Kenya, the deep Crescent Island Crater basin within Lake Naivasha, last stood dry at c. 2200 yr BP (Verschuren, 2001). At Sacred Lake, on the lower slopes of Mount Kenya, a study of plant leaf waxes indicate increased aridity shortly before 1700 yr BP (Konecky et al., 2014). In western Uganda, peak Mg levels within calcite deposited in Lake Edward point to a distinct century-scale long phase of intense evaporation around c. 1900 yr BP (Russell and Johnson, 2005); this evidence for pronounced regional aridity has also been recorded at a nearby Ugandan crater lake (Russell et al., 2007). Kiage and Liu (2006) have suggested that from 2500 yr BP a steady decline in tree cover, seen in pollen profiles, can be linked with a coeval increase in evidence for human activity, and that increased sedimentation rates are indicative of erosion caused by land clearance for agriculture. Examples that are given include the presence of *Elaeis guineensis* (wild oil palm) pollen grains found within the Lake Masoko sediment record (Vincens, 1989); recycling of tree pollen within sediments with high accumulation rates at Lake Tanganyika (Msaky et al., 2005) and coeval deforestation at Batongo and Katenga mires in Uganda (Morrison and Hamilton, 1974; Taylor, 1990). Whilst these are signs of deforestation, disturbance and change, in the absence of further distinct human indicators or archaeological evidence, assigning a

human cause to this disturbance is not possible. This is further supported by evidence for climatic change from Lake Challa, near Kilimanjaro, where a shift to relatively low values of the Branched to Isoprenoid Tetraether (BIT) index from bacterial cell-wall lipids have suggested a period of reduced rainfall between 2000 and 1800 yr BP (Buckles et al., 2016). On the coast of East Africa, a higher sea level was recorded after 3200 cal yr BP until around 2000 cal yr BP before falling below the present level at approximately 1400 yr BP (Punwong et al., 2017); this fall in sea level also coincides with a period of reduced rainfall seen at Lake Challa. Clearly, this was a period of pronounced climate variability, with considerable regional differences, and a time when people may or may not have initiated or accentuated environmental change. Despite this uncertainty, a period of extreme aridity does seem to have centred around 2000 yr BP.

Following this episode of apparently intense drought or extended dry seasons, much of East Africa appears to have experienced a transition to slightly wetter conditions between c. 1800 and 1500 yr BP. At Lake Naivasha this is evidenced by the refilling of the previously dry basin, followed by a relative high stand lasting until about 1400 yr BP (Verschuren, 2001). Similarly, reduced Mg values of calcite in Lake Edward for the period 1800 to 1600 yr BP (Russell and Johnson, 2005) suggest wet conditions on the western shoulder of the East African plateau, while at Lake Tanganyika, a contemporaneous humid phase is dated to between c. 1750 and 1450 yr BP (Stager et al., 2009).

Despite extensive forest clearance, as recorded on the mountains of Burundi, Rwanda, Tanzania, and Uganda (Bonnefille and Rioulet, 1988; Taylor, 1990; Jolly et al., 1997) some quite large tracts of forest remained intact. For example, a precursor of the present Bwindi-Impenetrable Forest remained forested while the surrounding region was extensively cleared. Why some areas were cleared and others not is difficult to decipher. One possibility is that there may have been some degree of protection imparted by forest dwelling communities likely to have been present at the time - such as a precursor to the modern Batwa - who restricted expansion of agricultural land (Hart et al., 1996). Currently there has been insufficient archaeological research on this time period or relevant ethnographic work, in these montane contexts, to allow us to even begin to understand how people might have perceived and used/avoided certain forested areas. However, the palaeoecological records do inform us that by approximately 2000 yr BP agriculture had spread within the western highlands of East Africa, and that areas of forest had been afforded 'protection'; this protection has continued to the present day, now under the guise of National Park legislation (Section 5.3).

3.2.iv. Environmental history from 1500 cal yr BP to present

The number of available palaeoenvironmental records covering the past 1500 years to present is greater than for the earlier time periods. Perhaps as a consequence, this increased wealth of data records a highly variable climate with quite a range of responses, although very large geographic gaps still remain. Variable climate has been seen at Lake Naivasha, Kenya where sedimentation dynamics observed from a sediment core demonstrated multiple fluctuations from shallow pond-like conditions to a lake extending approximately 150–250 km², with low stands corresponding to historically documented phases of drought (Verschuren et al., 2000).

Farther south, the record from Lake Tanganyika (Alin and Cohen, 2003) suggests increasingly wet conditions between 1200 and 1000 yr BP, while to the north in Lake Turkana, Mohammed et al. (1996) interpret the pollen record from this period as reflecting lower lake levels. Ryves et al. (2011) suggest there is substantial evidence for a widespread arid phase around 1000 to 800 yr BP across the East African region, citing records from lakes such as Lake Naivasha (Verschuren et al., 2000), Lake Emakat (Ryner et al., 2008), Lake Victoria (Stager et al., 2005), Lake Edward (Russell and Johnson, 2005) and Lake Kitagata (Russell et al., 2007). Ryner et al. (2008) suggest that this dry phase before 800 yr BP also coincides with drier conditions at Lake

Naivasha (Verschuren et al., 2000; Lamb et al., 2003) and Lake Edward (Russell and Johnson, 2007). In addition, a prolonged dry phase from 1250 to 550 yr BP has been recorded in the sediment record from Lake Masoko (Barker et al., 2000; Gibert et al., 2002; Vincens et al., 2003). The pollen data from Kasenda, Uganda (Ssemmanda et al., 2005) further supports this period of aridity, with a decline in forest taxa around 1100 to 1000 yr BP being attributed to this dry phase. Limited burning during the period c. 1050–950 yr BP in the Lake Simbi area, and during the longer period c. 1100 to 850 yr BP in the Naivasha area, may both reflect the wider region's generally dry conditions (Verschuren and Charman, 2008) with widespread fuel limitation (Colombaroli et al., 2014) across the drier savannahs of eastern equatorial Africa. It must be emphasized that for such ecosystem transitions it is challenging to assign cause and effect as they coincide with the rise of political complexity, and consequential intensification of human activities, at least in western Uganda (Taylor and Marchant, 1996; Taylor et al., 1999). Lake sediment records from western Uganda (Russell and Johnson, 2007; Russell et al., 2007; Mills et al., 2014) and Lake Tanganyika (Cohen et al., 1997; Alin and Cohen, 2003) record a humidity maximum from c. 800–500 yr BP, followed by sustained dry conditions. The high-resolution percentage Mg record from Lake Edward suggests that regional aridity at that time was comparable to that of climax drought conditions during the globally-expressed Medieval Climate Anomaly (Russell and Johnson, 2007). A similar pattern is shown by the 700-year biogenic silica record from Lake Malawi (Johnson et al., 2001), where moisture levels peaked about 500 yr BP followed by aridification; this culminated in a severe drought centred around 200 yr BP (Crossley et al., 1984; Owen et al., 1990). Lake Bogoria in the central Kenya Rift Valley reached a high level between 800 and 600 yr BP, followed by levels that were lower than present until c. 150 yr BP (De Cort et al., in press). To the north of Lake Bogoria, abrupt wetland formation at Lobo swamp is dated to 750 yr BP (Ashley et al., 2004; Driese et al., 2004). After this common initial stage of lake transgression, notable regional spatial differences developed, particularly in the amplitude and timing of hydroclimate variability. Sites such as Lake Naivasha (Verschuren et al., 2000) and Lake Challa (Buckles et al., 2016), indicate relatively humid conditions continued through the Little Ice Age. The signal from these eastern East Africa sites are in contrast, the western part of East Africa evolved toward dry conditions during the main phase of the Little Ice Age following an initial early-LIA wet period (Tierney et al., 2013).

At Lake Naivasha, this 500-year period of relatively moist climate was interrupted by episodes of lake-level decline (Verschuren et al., 2000; Verschuren, 2001) that were prominent enough to be recorded in regional vegetation (Lamb et al., 2003). These episodes have also been linked to oral traditions of droughts (cf. Webster, 1979; Verschuren et al., 2000). On the basis of the oral history, drought-induced famine and political unrest, have been suggested as the reasons for large-scale migrations occurring in the three drought periods around 560–580 (Wamara drought), 390–325 yr BP (Nyarubanga drought), and 190–160 yr BP (Lapanarat-Mahlatule drought) (Verschuren et al., 2000). However, as the temporal and spatial precision of the drought reconstructions from the oral history are questionable, such connections are of limited quantitative value and would benefit from further cross-disciplinary research. Equally, of far more importance for understanding these relatively short-term climate fluctuations across the region, is ensuring that the chronological information associated with the evidence for droughts is robust, and that it is both as precise and accurate as possible, as this period is notoriously hard to date using traditional radiocarbon methods alone (see Section 3.1ii).

If we turn to look at fire activity in the palaeoenvironmental record, we can see a mixed picture of climate-driven fire activity and human-induced activity, however, long-term palaeoecological records have shown that fire is generally more responsive to climate variability than has been previously thought, as most studies were based on satellite observations, which suffer from the disadvantage of only recording

short-term responses, not the longer-term climatic responses (Sankaran et al., 2005; Staver et al., 2011; Lehmann et al., 2014). Fire in the catchment of Lake Simbi, Kenya, seems to have been limited during the wettest episodes of the last millennium, as can also be seen in western Uganda (Colombaroli et al., 2014). However, conditions in the Lake Simbi catchment were never wet enough to allow wooded savannah to outcompete grasslands, implying that fire was sufficiently frequent to exert a positive feedback, impeding the encroachment of woody plants (Cochrane et al., 1999). At Lake Emakat, Tanzania, an increase in charcoal fragments c. 700 yr BP is contemporary with enhanced sedimentation suggesting in-wash associated with increased erosion (Ryner et al., 2008). The increase in sediment may also be linked to the increasing number of charcoal fragments c. 700–500 yr BP, in that the surrounding slopes may have become subject to increased erosion after stabilising vegetation had been burnt away. Frame et al. (1975) also propose that the present vegetation mosaic of woodland and bush in the Lake Emakat catchment is a result of extensive forest clearings by early agropastoralists in the Crater Highlands. This sedimentary and vegetation evidence, when combined with evidence from linguistic and archaeological sources (Sutton, 1971, 1993; Fosbrooke, 1972; Ehret, 1999, 2001), may point to an expansion of human population levels from c. 700 yr BP in northern Tanzania, however this link is currently unproven. At Lake Duluti (Öberg et al., 2012, 2013) burning was generally limited during both the wettest (ca. 600–400 yr BP) and driest episodes (ca. 800–730 and 200–150 yr BP; Stager et al., 2005) of the past millennium. Considering that fire only becomes more prevalent in wetter periods when people are involved, notably from 300 yr BP (Colombaroli et al., 2014), it would appear that climate was driving the fire regime at Lake Duluti. Coastal areas of East Africa show a low sea level was present between 1400 and 100 yr BP (Punwong et al., 2017). However, over approximately the past 100 years there have been moderate sea level rises until the present day that probably relate to global sea-level rise during the last century (Stocker et al., 2013).

Although the Little Ice Age continued from 630 to 100 yr BP, people also increasingly dominated the shaping of the environment from 300 yr BP, therefore it is worth examining this more recent period (300–present) in its own right. The leaf-wax δD time series from Sacred Lake on Mount Kenya attests to wetter conditions between c. 300–130 yr BP (Konecky et al., 2014). Wetter conditions around 300 yr BP gave way to a widespread arid phase from 150 to 100 yr BP (Ryves et al., 2011), which had the effect of desiccating many of the lakes in the region (Bessems et al., 2008); however, from around 150 yr BP, these dry conditions were followed by a wetter phase. A general pattern of substantially increasing lake levels in the nineteenth century CE (150–50 yr BP) (Verschuren et al., 2002; Bessems et al., 2008), was followed by a period of wet, but more stable, conditions (50 yr BP to present) (Russell and Johnson, 2007; Bessems et al., 2008). Superimposed on these general patterns are shorter events, such as the period of increased rainfall across East Africa c. 90–70 yr BP (Nicholson, 1996b) which may have also caused a dramatic rise in Lake Duluti, Tanzania, seen to occur around 50 yr BP, potentially turning an area of swamp into an open water lake (Öberg et al., 2012). After a period of prolonged drought up to 300 yr BP wetter conditions are also attested to at Munsia archaeological site (e.g. Nicholson, 1996b; Taylor et al., 1999; Robertshaw and Taylor, 2000; Verschuren et al., 2000; Thompson et al., 2002; Alin and Cohen, 2003; Robertshaw et al., 2004) forest expansion began to occur again between 300 and 100 yr BP. However, using records from Lake Baringo and two shallow crater lakes in western Uganda, the combined evidence suggests that the nineteenth century CE was drier, on average, than the 20th century (Nash et al., 2016). Following the dry period at the beginning of the nineteenth century (Stager et al., 2005; Bessems et al., 2008), when the level of Lake Simbi was low, biomass burning increased from c. 80 yr BP and peaked in the first decade of the twentieth century. The lowstand noted at Lake Simbi is largely coeval with evidence of drier conditions across eastern Africa at approximately 150–100 yr BP (Nicholson, 2000; Verschuren et al.,

2000; Bessems et al., 2008; Ryner et al., 2008). The water levels of Lake Tanganyika and Lake Rukwa, established from historical and geographical information, were low until 160 yr BP (Nicholson, 2001). In the Central Rift Valley, Kenya, a period of very low water levels and/or elevated salinity is dated to 130–110 yr BP (Verschuren et al., 2000) at which point the shallow lakes of Nakuru and Elementeita stood completely dry (De Cort et al., 2013).

Due to local and regional differences, lags in response time of vegetation and water levels, and the general lack of precision in radio-carbon dating in this period, accurately detecting and dating decadal-scale events may not be possible in the palaeoenvironmental records, which leaves the potential for a slightly ‘blurred’ interpretation of climate from these records alone. A more precise and potentially more accurate form of information about conditions for this period comes from historical sources.

The reduction in water availability between 150 and 100 yr BP likely contributed to a famine dated to 120 yr BP in eastern Africa (Hartwig, 1979) that has been claimed to have triggered extensive population migrations and social upheaval (Anderson, 2016). Nash et al. (2016) note that historical records from Burton (1860) and Krapf (1860) describe famine and drought occurring from 130 to 110 yr BP in the Pangani Valley, Tanzania and in Mombasa, Kenya. Nash et al. (2016) suggest that this dry period began around 165 yr BP, and using this date as a point of comparison, it can be seen in Nicholson and Yin’s (2001) water-balance model that rainfall within the catchment of Lake Victoria c. 165–115 yr BP was roughly 13% below the twentieth century mean. Again, this falls broadly within the 150–100 yr BP dry phase/drought period. Nonetheless, it is important to bear in mind that ‘droughts’ and ‘famines’ are not directly equivalent, the former being natural phenomena while the latter are well-known to be primarily (or at least partially) social, economic and/or political creations (e.g., Ball, 1976; Scrimshaw, 1987; Vaughan, 1987; Maddox, 1990; McCann, 1990). Moreover, within the palaeoenvironmental literature it is only when a dry period is associated with the potential to affect people that the discourse changes from apparently neutral terms such as ‘dry periods’ or ‘aridity’, to ones that are more socially-loaded, for example, ‘drought’ and ‘famine’.

Historical and palaeoclimatic records show that there was a major drought across eastern Africa in the late-nineteenth century CE (Gillson, 2015). The “Great Ethiopian Famine” from 1888 to 1892 CE is thought to have cost the lives of one third of the country’s population, but the famine was not purely restricted to Ethiopia. Data from Lakes Victoria, Chew Bahir and Naivasha show a sharp fall in lake level in the late 1890s (Nicholson, 1996a). The Maasai know this period as ‘Emutai’ – to wipe out (Saitoti and Beckwith, 1980; Waller, 1988) and massive mortality has been documented (Illife, 1987). Epidemics of bovine pleuropneumonia (BPP) and rinderpest killed cattle and wildlife in many areas from 1883 to 1891; this was quickly followed by an epidemic of smallpox that devastated the human population in 1892 (Saitoti and Beckwith, 1980). Cattle raiding between different ethnic groups and between different sections of the same groups began shortly after the onset of rinderpest; and continued raiding of stock and crops exacerbated the social fragmentation precipitated by the smallpox epidemic. Drought followed, and the rains failed completely in 1897 and 1898. At this time, rinderpest reappeared and persisted, spreading south beyond the Zambezi River and resulting in severe famine across large areas of eastern and southern Africa by 1899, no doubt exacerbated within the context of developing antagonism between European settlers and many African communities (Ofcansky, 1981; Waller, 1985).

Following the onset of the colonial period (c. 100 yr BP), human impact further intensified with population increases that resulted in major vegetation changes while rainfall has become increasingly variable. During the 1950s, the equatorial latitudes were comparatively dry and then relatively wet during the 1960s with exceptional rainfall in 1961 (Conway, 2002) leading to peak river discharge and peak levels

for Lake Albert (Beuning et al., 1997; Sutcliffe and Parks, 1999), Lake Victoria (Kendall, 1969; Sene and Plinston, 1994), Lake Naivasha (Åse et al., 1986) and Lake Tanganyika (Nicholson, 2000) in 1963–1964. More frequent and intense dry periods have occurred in eastern Africa over the past century (Graef and Haigis, 2001; Funk et al., 2013; Hoell and Funk, 2014; Nicholson, 2014; Nash et al., 2016). Complex patterns and high spatiotemporal variability in precipitation is clear for much of East Africa over the past century and a general trend towards increased interannual variability of rainfall over recent decades is evident (Nash et al., 2016).

3.3. Evidence for human change across the East African landscape

The challenge of making accurate inferences about human history is extremely demanding and should not be underestimated - it requires the integration of archaeological, historical, genetic and linguistic data alongside palaeoenvironmental evidence. As with the synthesis of information derived from the accumulated sediments, a range of techniques is combined to reconstruct how cultures and societies have changed through time. This range of evidence varies from direct analysis of past occupation layers revealed by archaeological investigations and associated artefacts such as pottery, to documentary evidence. For example, traditionally in archaeology, ceramic artefacts have been used to establish patterns of regional and temporal succession of pottery styles, which are then used to trace the movements and interactions of different cultural groups, an intellectual history reviewed and critiqued for East Africa by Ashley and Grillo (2015). This approach has been widely discredited as archaeologists have long realised the limits of equating “pots and peoples” (Kramer, 1977; Lane, 2015a) and thus of

using material culture as a proxy for identity and, by extension, migration (Ashley et al., 2016). Increasingly, alternative approaches have been taken to examining past population movements and interactions in East Africa, including technological analyses and geochemical sourcing of artefacts (e.g., Goldstein and Munyiri, 2017; Merrick and Brown, 1984), stable isotope analyses (e.g., Kiura, 2008; Chritz et al., 2015; Janzen, 2015), modern DNA from people (e.g., Tishkoff et al., 2007; Henn et al., 2008; Tishkoff et al., 2009; Ranciaro et al., 2014) and livestock (e.g., Hanotte et al., 2002; Gifford-Gonzalez and Hanotte, 2011), and increasingly ancient DNA from people as well (Gallego Llorente et al., 2015; Skoglund et al., 2017). These and other analyses show that the Holocene cultural record of East Africa is not characterised by neatly bounded developmental stages: rather, the human landscape of East Africa over the past six millennia was characterized by highly fluid economic and social “mosaics,” landscapes of interaction between people with distinct subsistence strategies and cultural traditions (Kusimba and Kusimba, 2005; Crowther et al., 2017). This is exemplified by the fact that sites previously classified as terminal (Holocene) Later Stone Age (LSA), and those classified as Iron Age (IA), typically subdivided into the Early and Later Iron Ages (EIA and LIA, respectively), two ostensibly distinct chronological and cultural stages, are often in fact contemporaneous with one another and found in the same geographic area (e.g. Ambrose, 1984; Helm et al., 2012). Indeed, in some cases the occupants of sites previously categorized as LSA or IA on the basis of their associated material culture and subsistence evidence are now known to have interacted (Shipton et al., 2013; Crowther et al., 2017). Assertions as to the date of a particular site based on artefactual evidence should thus be treated with caution, particularly within the older literature, and it is now clear that there is

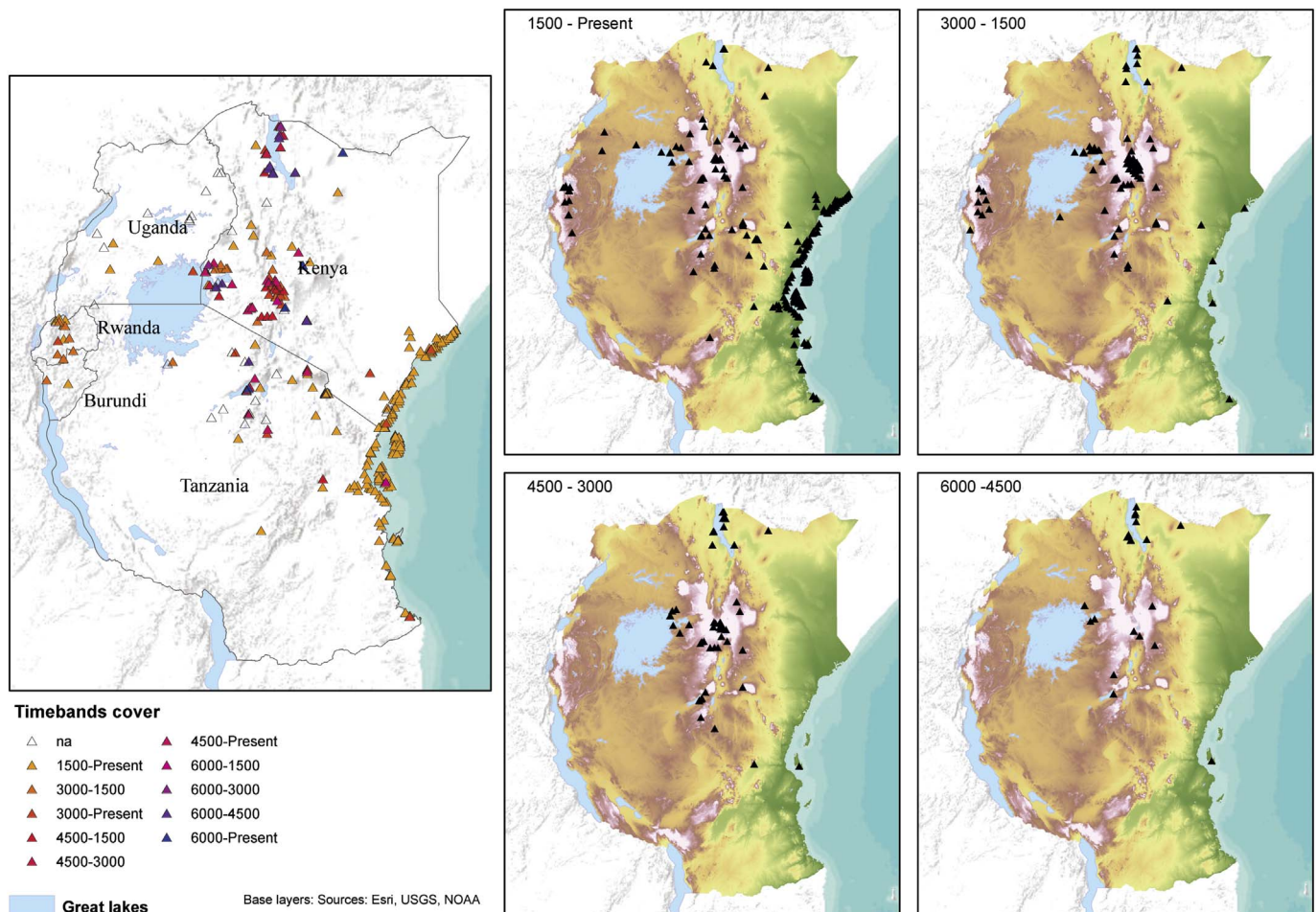


Fig. 12. Plots of archaeological sites with elevation (SRTM-250 m) by time periods.

tremendous heterogeneity across space and time that defies these categorical definitions.

While studies of Holocene stone-using foraging and pastoralist societies in eastern Africa are documented primarily through archaeological evidence (reviewed below), studies of iron-using farming communities have relied much more heavily on the fields of historical linguistics (e.g., Vansina, 1984, 1995, 1999; Grollemund et al., 2015), and increasingly, modern population genetics (e.g., Tishkoff et al., 2009; Patin et al., 2017), in order to trace the spread of both farmers, and of Bantu languages, across the continent. Our understanding of this so-called ‘Bantu expansion’ has evolved from a vision of a neat “package” of crops, iron technology, and Bantu-language speaking peoples, to a disentangling of these distinct factors and their archaeological, linguistic, and genetic signatures, which are now understood not to move in tandem (as discussed by, for example, Hiernaux, 1968; de Maret, 1985, 2013; Scheinfeldt et al., 2010; Crowther et al., 2017). Archaeology and especially archaeobotany have traditionally played a more limited role in our understanding of the spread of farming (but see Russell et al., 2014), which may be partially due to the lower visibility of these sites relative to those of stone-using peoples. A lack of archaeobotanical research in the region until recently (Giblin and Fuller, 2011; Walshaw, 2015; Crowther et al., 2016b, 2017), is nevertheless also a significant factor.

Although the amount of data from archaeological studies has greatly increased, many gaps remain. These gaps in some cases reflect fashions in academic research, and in others result from pragmatic issues like ease of site access from major roads or settlements; factors that equally affect the distribution of palaeoenvironmental data, as discussed in

Section 4 below. The coverage of archaeological surveys is certainly not comprehensive, as reflected in large blank areas on maps of site distribution (Figs. 12, 13, 14), and is biased towards better-investigated regions, time-periods, and forms of evidence (like pottery or stone tools), with a ratchet effect whereby discoveries in one study area and dating to a particular time period tend to prompt additional searches for the same. The Pastoral Neolithic (PN) period, for example, is particularly well-known from the Central Rift Valley of Kenya, whereas the EIA is better-documented in the Lake Victoria Basin and along the Indian Ocean coast (Fig. 12); whether this reflects true distributions (and is thus informative about human choices), or results from sampling patchiness, is difficult to ascertain on present evidence. It is worth reiterating, however, that designations formerly regarded as distinct cultural-historical entities — terminal LSA, PN, and EIA — at least partially overlap in space and time, and distinctions between them are primarily based upon inferred subsistence and material culture traditions.

Recognisable pollen types related to human activities can also be a very useful addition to direct archaeological information, but pollen records are often a poor proxy for relatively subtle changes in vegetation (Marchant et al., 2004). An additional source is the modern biodiversity of plants used in agriculture, such as bananas and plantains: studies of the genetics of living specimens (and names given to them) can reveal histories of domestication and the rate, direction and timing of spread (Rossel, 1995). The cultivated crops commonly found in East Africa have distinct origin centres (reviewed by Fuller and Hildebrand, 2013; Crowther et al., 2017), with pearl millet (*Pennisetum glaucum*) and cowpea (*Vigna unguiculata*) originating in West Africa, finger millet

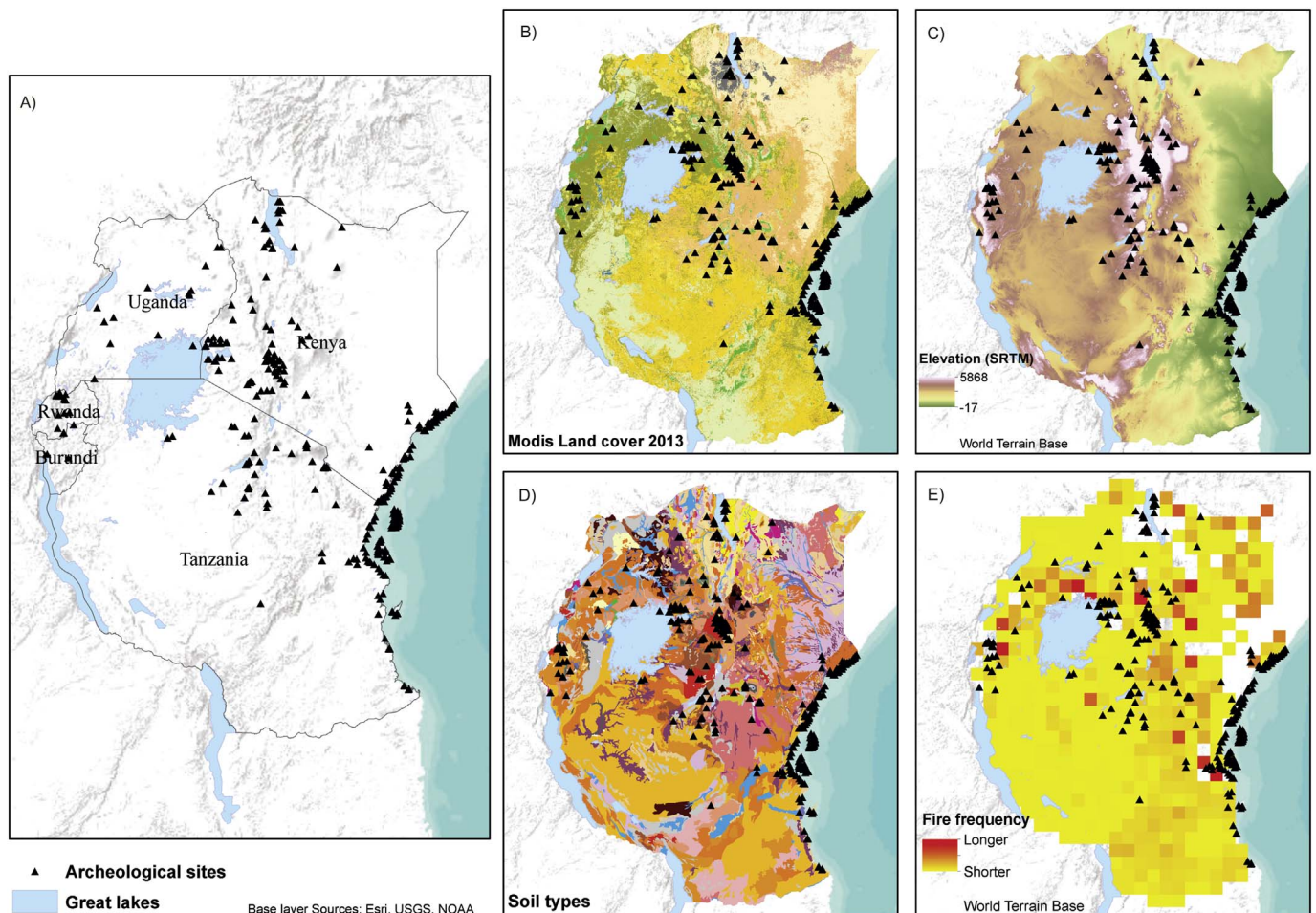


Fig. 13. Plot of archaeological sites distributed over maps of topography: A) vegetation, B) MODIS land cover classes (2013), C) elevation (SRTM-250 m), D) soil (Soil Atlas of Africa), and E) fire return interval. Map legends are presented in Figs. 2 and 4 and references in the captions for those figures.

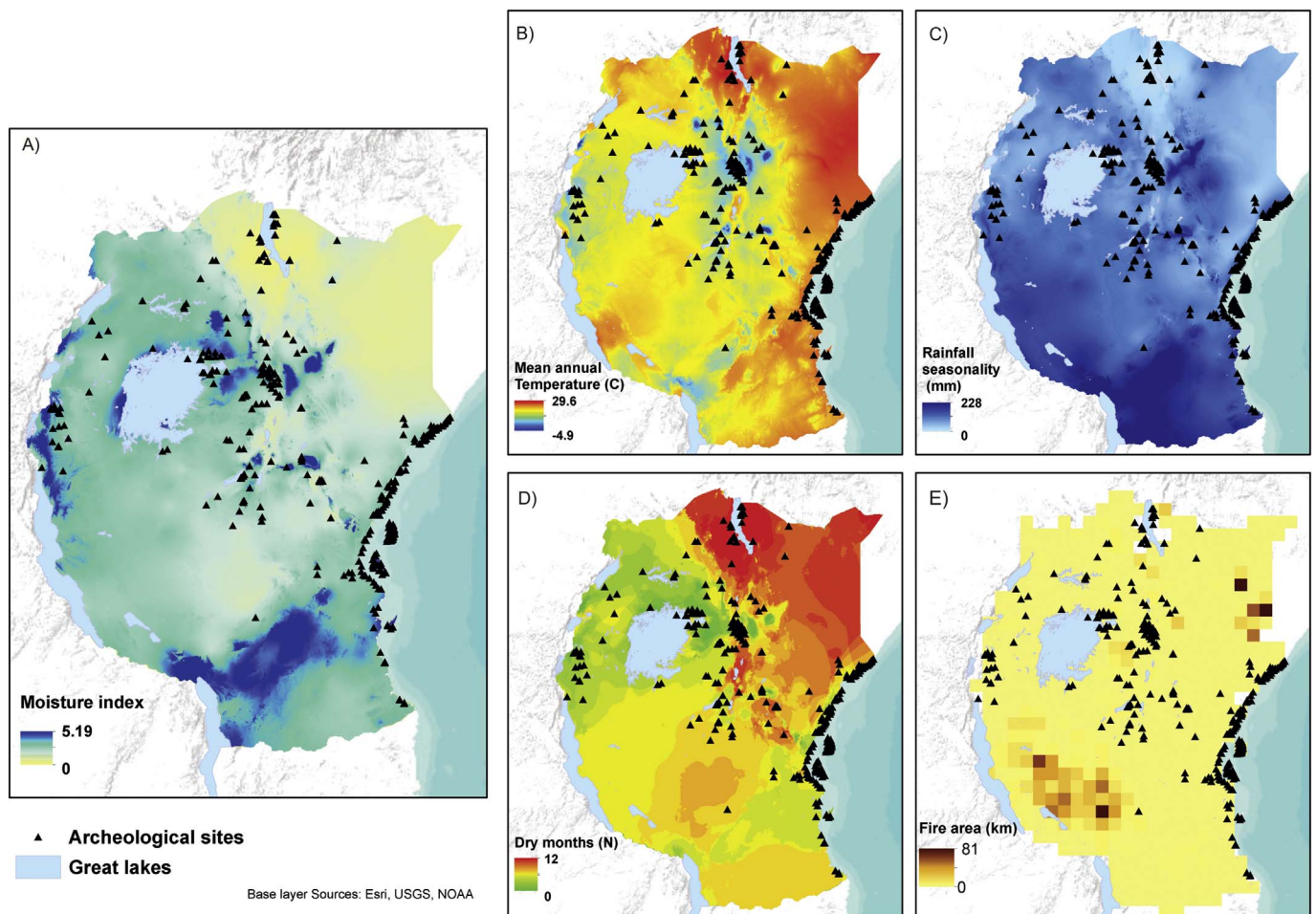


Fig. 14. Plot of Archeological sites against: A) moisture index. B) mean annual temperature. C) rainfall seasonality. D) number of dry months (AfriClim 3.0). E) burned area. Map legends and references are presented in Fig. 3 and caption.

most likely coming from the Ethiopian highlands, and sorghum possibly from northeastern Sudan (Harlan et al., 1976; Harlan, 1993). Exotic crops such as Asian rice (*Oryza sativa*), banana, Asian yam (*Dioscorea alata*), and taro arrived via Indian Ocean exchanges (Boivin et al., 2013, 2014; Crowther et al., 2016a, 2016b). Microfossils of maize have been recorded from the Pare Mountains (Tanzania) and Lake Naivasha (Kenya) from approximately 250 yr BP (Finch et al., 2017), on the Laikipia Plateau (Kenya) by c. 200 yr BP (Taylor et al., 2005), and Munsu Swamp after c. 170 yr BP (Lejju et al., 2005), suggesting that this crop arrived on the Indian Ocean coast from the New World before rapidly spreading inland, presumably along established caravan trade routes. Tracing the histories of such plants is crucial as they can be intimately associated with human populations (e.g., Crowther et al., 2016a, 2016b). Evidence cited for food production and type of subsistence falls primarily within four categories; i) botanical and faunal remains from archaeological sites, ii) vegetation records obtained from perennially wet areas, iii) settlement characteristics including deposits of, for example, animal dung, and iv) genetic evidence from living crops and their wild ancestors (Neumann and Hildebrand, 2009; cf. Piperno et al., 2002). Other information on past human activity comes from a range of impacts and influences on the present-day ecological composition of vegetation communities.

Information on past human activities is often derived from sedimentary sequences based upon the assumption that major changes in human activities will impact upon the sediments by altering catchment conditions. Such records are often particularly sensitive to recording the environmental effects of human populations, particularly in sedimentary basins, since these both contain resources that attract human

populations (water; deep soils) and allow for the accumulation of thick sediment sequences. Nevertheless, it may be that human actions are not commuted to the sedimentary record - an absence of human indicators does not mean humans were absent - but we should be wary of assuming that the onset of soil erosion, for example, can be readily equated with vegetation clearance, with all the attendant consequences such assumptions can have (e.g. Heckmann, 2011; for discussion see, e.g., Lane, 2009). Studies of sedimentary sequences from East Africa in general have tended to rely on relatively few proxy indicators of human impact such as certain pollen and diatom types, and the abundance of charcoal (Lejju et al., 2005; Rucina et al., 2010; Finch et al., 2017; Hawthorne et al., 2017). Fire, for example, is now recognised as an important agent of vegetation dynamics in tropical rainforests with humans clearly playing a major role in the distribution of vegetation communities on a global scale (Haberle and Chepstow-Lusty, 2000; Haberle et al., 2001). Thus, it is often assumed in East African palynology that the introduction of agriculture, in the absence of direct indicators such as pollen from domesticated plants, is marked by evidence of forest clearance and burning (e.g., Rucina et al., 2010; Finch et al., 2017).

This assumption may hold for some activities, but shifting cultivators often make use of natural forest gaps or move with sufficient regularity to allow forest recovery (e.g. Fairhead and Leach, 1996), and indeed some forms of agriculture could be said to promote tree cover, such as low intensity cultivation of oil palm (*Elaeis guineensis*), or the protection of trees to provide shade to crops grown within so-called 'forest gardens' (e.g. Stump and Tagseth, 2009). In other parts of the world, hunter-gatherers/foragers are also known to have used fire as a

vegetation management tool (e.g., Head, 1996; Lightfoot et al., 2013).

This having been said, a reliance on charcoal as an indicator of human presence within landscapes can be problematic, as it ignores natural vegetation dynamics and the mass of evidence showing both that vegetation burns naturally and that fires are an important natural part of ecosystem change. For example, the Ahakagyeyi and Muchoya swamps in southwest Uganda have yielded sedimentary records that extend into the last glacial period: samples from the entire span of sediments recovered have been analysed and each one has contained a significant amount of charcoal (Taylor, 1990, 1993). Indeed, on the basis of the charcoal record from Muchoya, fires appear to have been every bit as common at the end of the last Ice Age as they are today, yet anthropogenic forest clearance based on pollen variability has occurred only since the third millennium BP (Marchant and Taylor, 1998). Down-core fluctuations in charcoal abundance at Rusaka Swamp also show a similar pattern (Mohammed et al., 1996).

Pollen, similarly, can be a relatively blunt tool to trace human impacts: samples from Ahakagyeyi Swamp suggest that ‘regenerating’ and ‘stable’ patches of forest co-existed throughout the Holocene (Taylor, 1993). There are a number of possible reasons for unexpectedly weak signals of human activity in pollen records. First, incompatible or loose chronologies may mean that researchers are looking for evidence in the wrong part of the sedimentary column. Second, some past societies may indeed have trodden lightly on the landscape, particularly where population densities were low and/or populations were highly mobile.

While it has long been argued that low population densities and/or high levels of mobility would also make pastoralist groups hard to see archaeologically (Smith, 2008), in fact a growing body of evidence demonstrates that pastoralist activities can be detected, often through micromorphological and/or geochemical approaches, as well as through analysis of microfaunal communities (Simons and Ambrose, 2008; Muchiru et al., 2009; Weissbrod, 2013; Petek, 2015; Boles and Lane, 2016; Lane, 2016). Indeed, past generations of East African pastoralists left highly visible traces across the landscape, in the form of abundant stone tools and animal bone middens, as well as less visible but detectable traces of dung and ceramic scatters.

Of equal relevance to discussions of the detectability of change is the issue that human-induced alterations in some vegetation types, such as humid rainforest, may simply remain hidden in sedimentary records because the change was not sufficient to induce a change in the proxy. A good example of this is ‘closed’ (or amplifier) lakes in semi-arid parts of the region. Although these are the preferred locations for reconstructing past variations in effective precipitation, the nature of the ecosystems surrounding these lakes mean that the palaeoenvironmental proxies recorded in lake sediments may be very insensitive to change. Such systems might be sensitive to relatively small fluctuations in rainfall, therefore, but they may not record human impacts of low intensity. Indeed, it should also be remembered that the relevant part of the sediment column may be missing, either as a result of non-deposition or post-depositional erosion. Thus, sedimentary evidence, as with other sources of data, should be used with caution – an approach that will be adopted within this review.

The evidence for human change across East Africa will be presented in a series of steps that are identical to those of the environmental information, in order to enhance comparability (Figs. 12, 13 and 14). It should nevertheless be reiterated that the archaeological record does not fit easily into a series of stages, and especially for the latter half of this six-millennia period, mosaics of foragers and food producers, and later also including urban dwellers, defined the landscape (Kusimba and Kusimba, 2005).

3.3i. Archaeological history from 6000 to 4500 yr BP

At the opening of our six millennia review, the East African landscape was occupied by fishers and foragers associated with LSA lithic technological traditions. While often viewed as indistinct, there is in fact tremendous diversity amongst Holocene LSA sites, both in terms of

technological variability, and the settlement and subsistence strategies of their occupants. A key challenge to understanding this variability is the poor temporal resolution that characterizes much of Holocene archaeology in the region. In fact, there are extremely few radiocarbon dates falling within the 6000–4500 BP range (see SM2). Whether this reflects sampling patchiness, or a true decrease and/or dispersal in populations, remains to be understood. In this section, we discuss fishing and foraging traditions that both predate, and are thought to continue into, the sixth and early-fifth millennia BP. Naturally, this review highlights the best-researched areas, and will regrettably overlook others where few or no sites have been documented. This patchiness may reflect research histories, rather than true distributions of people and their cultural traditions in any given window of time.

In the Turkana Basin, fishing communities are documented from as early as the Pleistocene–Holocene transition and are associated with almost exclusively aquatic fauna, bone points or harpoons, and at some sites, small numbers of ceramics (for reviews, see Stewart, 1989; Yellen, 1998; Prendergast and Beyin, 2017); recently, human remains recovered at Nataruk were interpreted as evidence of violent intergroup conflict amongst fisher-foragers of this era (Lahr et al., 2016; cf. Stojanowski et al., 2016). Given that lake levels drop dramatically at c. 6000 yr BP (Garcin et al., 2012; Wright, 2014), one might expect such settlements to disappear. Unfortunately, radiocarbon dating remains seriously limited for the early Holocene sites, both in terms of contextual association and the materials dated, as discussed by Beyin et al. (2017). On current evidence, there are indeed very few fishing settlements extending beyond 6000 yr BP, other than isolated radiocarbon dates from GaJi3 at Koobi Fora (Barthelme, 1985) and Bb-14 at Lothagam Hill (Yamasaki et al., 1972). These fall into the sixth or early fifth millennia BP, as do some of the U-series dates on skeletal remains from the Nataruk “massacre” (Lahr et al., 2016). Whether these dates accurately reflect activities at these sites is open for debate, though we know that aquatic resource exploitation occurred in the Turkana Basin in the past two millennia (Robbins, 1980, 1984), continuing until today (e.g., Sobania, 1988). Concomitant with the mid-Holocene drop in lake levels, beginning as early as c. 5000 yr BP, this area also witnessed the arrival of the first livestock herders of East Africa. We discuss this phenomenon further below.

Around Lake Victoria there are numerous sites dating to c. 8000–2000 yr BP, all sharing a type of ceramic known as Kanyore, as well as an aquatic subsistence focus and a quartz/quartzite-based lithic technology (Seitsonen, 2010). Kanyore sites are found in Uganda, Kenya, and Tanzania, nearly always near the shorelines or palaeoshorelines of Lake Victoria, or along its tributaries (reviewed by Dale and Ashley, 2010; Prendergast, 2010). Kanyore pottery has also been found in contexts associated with fishing in northwestern Uganda (Schmidt, 2016), and in rockshelters in grasslands and near a soda lake (Eyasi) in northern Tanzania; these finds are associated with foraging but have little to no association with fishing (Mehlman, 1989; Prendergast et al., 2007; Prendergast, 2011). In these instances, occupations with Kanyore ceramics appear indistinct from roughly co-occurring aceramic LSA occupations at these and other sites in the region. Across East Africa, the Kanyore chronology is problematic, and notably most sites fall on either side of the c. 6000–4500 yr BP window, raising the question of if and why there might be a hiatus in otherwise relatively unchanged ceramic and aquatic exploitation traditions. However, a handful of Kanyore occupations fall into this timeframe, including at Mumba Rockshelter in the Eyasi Basin, where ceramics were directly dated (Prendergast et al., 2014).

Away from lakes and rivers, foragers occupied rockshelters, and presumably undetected open-air sites, in the plains and highlands of East Africa throughout the Holocene (for a review, see Kusimba, 2014). The best-documented areas for Holocene LSA occupations are the Central Rift Valley of Kenya (Ambrose, 1982, 1984); Lukenya Hill in southern Kenya (Gramly, 1975; Bower and Nelson, 1978; Kusimba, 2002); the southeastern plains and coastal hinterland of Kenya (Abungu

and Muturo, 1993; Kusimba et al., 2005; Helm et al., 2012; Shipton et al., 2013); and the highlands and some lowland lake basins of north-central Tanzania (Inskip, 1962; Odner, 1971a, 1971b, 1971c; Masao, 1979; Mehlman, 1989; Prendergast et al., 2013). Some of these sites have dated samples falling within the 6000–4500 yr BP window, but the majority fall on either side of this gap. Superficially, many of these occupations seem similar: they are documented in rockshelters, sometimes with paintings that may or may not be associated; they share LSA lithic technologies, which have been little studied (but see Ambrose, 1984; Mehlman, 1989; Barut, 1994; Wilshaw, 2016); and their subsistence strategies include hunting of mainly large- and medium-sized game (Mehlman, 1989; Prendergast, 2011; Prendergast et al., 2013), though in more forested locations, trapping of smaller game was important (e.g., Ambrose, 1984; Marean, 1992). While other components of the modern hunter-gatherer diet do not preserve (e.g. honey) or have not been systematically sought (e.g. plants), it is likely that animal foods at prehistoric sites were part of a much broader diet.

The paucity of radiocarbon dates for both fishing and terrestrial hunting sites in the 6000–4500 yr BP window is notable, especially because many of the subsistence and technological traditions observed in the early Holocene are also observed in the later Holocene, and in one case (Kansyore) there are also very strong ceramic similarities on either end of this gap. At one site, the “Eburran” hunter-gatherer shelter of Enkapune ya Muto in the Central Rift Valley, this hiatus is very well documented within a long series of earlier and later dates, and might be attributable to site abandonment for higher altitudes as conditions became drier (Ambrose, 1998). At other sites, however, so few dates are available that it is difficult to know whether the gap c. 6000–4500 yr BP represents a sampling error or a true hiatus. What we can say is that on current evidence, it seems that populations at this time were living lightly on the landscape, employing subsistence strategies that are not expected to involve major vegetation clearance.

3.3ii. Archaeological history from 4500 to 3000 yr BP

Beginning c. 5000 yr BP, East Africa witnesses the first appearance, and an initial slow spread, of food production, as well as a continuation of fishing and foraging activities described above. This marks the beginning of the Pastoral Neolithic (PN) at c. 5000–1200 yr BP (for reviews see: Bower, 1991; Gifford-Gonzalez, 2005; Marshall et al., 2011; Wright, 2014; Lane, 2013a; Lane, 2013b). Unlike other world areas, mobile livestock herding of cattle (*Bos taurus*), sheep (*Ovis aries*) and goat (*Capra hircus*), aided by donkeys (*Equus asinus*), preceded sedentary farming in much of prehistoric Africa (Marshall and Hildebrand, 2002). Increasing aridity in the Sahara during the mid-Holocene may have been the driving force leading to the southward movement of pastoralists into East Africa (Maslin, 2016). In this region, domestic caprine and cattle remains first appear in the Turkana Basin c. 4500–4000 yr BP at the site of Dongodien (GaJi4), and possibly at neighbouring GaJi2 (Marshall et al., 1984), and are associated with “Nderit” ceramics and LSA lithic technology. Elsewhere around Lake Turkana, from c. 5000–4000 yr BP, direct evidence of herding is present but scarce, and Nderit ceramics have been taken as a proxy for pastoralist communities. However, the scarcity of livestock remains likely reflects a lack of extensive excavation at habitation sites like Dongodien, rather than a true absence of evidence. Increased research at megalithic mortuary sites around Lake Turkana, many of which also have Nderit pottery, have clarified their chronology and more firmly link them to mobile pastoralism (Hildebrand and Grillo, 2012; Grillo and Hildebrand, 2013); at the site of Jarigole, clay livestock figurines may offer additional support (Nelson, 1995). Importantly, these megalithic mortuary sites, which were constructed relatively rapidly around the Turkana Basin, never extend beyond this area, despite finds of Nderit ceramics in central and southern Kenya and possibly into northern Tanzania (Gifford-Gonzalez, 1998). This slow start to the spread of pastoralism has been attributed to zoonotic diseases, aridity, and the presence of indigenous foragers or other social factors

(Marshall, 1990; Gifford-Gonzalez, 2000; Marshall et al., 2011). The appearance of mobile herding around Lake Turkana coincides with dropping lake levels (Grillo and Hildebrand, 2013; Wright et al., 2015), and, as noted above, is possibly accompanied by a reduction in fishing sites and diversification of fishing strategies (Stewart, 1989), though this may be an artefact of uneven archaeological sampling. Fish remains continue to appear at sites with livestock, but barbed bone points and exclusively aquatic diets appear to all but disappear in the mid-Holocene arid period.

South of Lake Turkana, mobile herders appear in isolated occurrences throughout the fourth millennium BP, but there is little direct evidence of their activity (Wright, 2014). At the Eburran forager site of Enkapune ya Muto in the Central Rift Valley, caprines appear in an otherwise wild faunal assemblage beginning possibly as early c. 4500–4300 yr BP and become common at the site by c. 3700–3200 yr BP (Ambrose, 1998). At Wadh Lang'o, a Kansyore site with later occupation phases near Lake Victoria, caprines and cattle appear after c. 4000 yr BP, again being minor components of otherwise fisher-forager assemblages (Prendergast, 2010); the same is true in the Kansyore horizons at the multi-period sites of Usenge 3 at c. 3500 yr BP (Lane et al., 2007) and Gogo Falls, where dating of domesticates is problematic (Robertshaw, 1991; Karega-Munene, 1993). Thus, the initial southward spread of livestock seems to be patchy and involving the agency of existing (fisher-) forager groups. Also in the early fourth millennium BP, forager occupations are well-documented, especially in the Rift Valley and adjacent highlands. It is remarkable that many of the Holocene LSA occupations of central Tanzania have radiocarbon dates primarily clustering around c. 4000 yr BP (Odner, 1971a, 1971b, 1971c; Masao, 1979; Mehlman, 1989; Mjema, 2008; Prendergast et al., 2013; Prendergast et al., 2014). Given the small number of dates, this could be a sampling issue, but it remains a notable trend.

A recent review of the radiocarbon dating evidence suggests that, aside from the exceptions noted above, there are no sites with livestock beyond Turkana that predate the end of the fourth millennium BP (Grillo et al., in press). While Nderit pottery, like that of the Turkana Basin in the fifth millennium BP, does appear at multiple Kenyan sites (Gifford-Gonzalez, 1998, 2005), and possibly as far south as Lake Eyasi in Tanzania (Mehlman, 1989), these findings are scattered and not clearly associated with livestock. True PN sites, marked by abundant livestock remains, as well as novel ceramic styles and stone bowls, do not appear until after c. 3000 yr BP. This late date may be due to a heavy reliance at PN sites on bone apatite, a notoriously unreliable material for dating, as well as numerous problems of contextual association (Collett and Robertshaw, 1983). More recently obtained dates from PN sites in southeastern Kenya (Wright, 2005) and northern Tanzania (Prendergast et al., 2014; Grillo et al., in press) slightly pre-date the c. 3000 yr BP mark; redating more northerly sites is thus essential to reassess the tempo of the spread of herding. Indeed, the opening up of grasslands in Kenya and Tanzania after c. 3500 yr BP, as Rift Valley lakes shrank or disappeared altogether and forests receded, may have helped facilitate the spread of pastoralism, and this seems a more likely starting point for the spread of the PN (Lane, 2013a).

In summary, the period c. 4500–3000 yr BP is best characterized as one in which foragers and (in the Victoria Basin) fisher-foragers dominated the landscape, with livestock herding being mainly confined to the Turkana Basin, other than isolated occurrences. The latter seem to reflect a trickle, possibly involving the agency of foragers, of livestock moving south. One therefore assumes a marginal and highly localized impact upon vegetation that might be associated with grazing. However, renewed efforts at radiocarbon dating, and further palaeoecological work, have the potential to change this narrative.

3.3iii. Archaeological history from 3000 to 1500 yr BP

The third millennium BP is characterised by the fluorescence of specialized pastoralism across much of East Africa, while foraging and fishing communities also continued to thrive, in some cases interacting

with in-migrating herders. This widespread dispersal into the Rift Valley and grasslands of central and southern Kenya, and ultimately into Tanzania, is frequently viewed as a response to ameliorating climatic conditions, with rainy seasons becoming biannual, but rainfall itself less predictable (Marshall, 1990, 2000; Marshall et al., 2011). Both the number of PN sites, and the extent of research on them (particularly in central and southern Kenya), have enabled a relatively good understanding of the material culture, subsistence strategies, settlement patterns, and mortuary traditions of specialized herders of this era (Lane, 2013a, 2013b). These studies have enabled two broad groupings of the PN, both dating to c. 3000–1200 yr BP (Ambrose, 1984; Robertshaw, 1988). Elmenteitan sites, found in geographically restricted areas of southwestern Kenya, are defined by distinctive and relatively uniform material culture and by consistent access to particular obsidian sources. By contrast, Savannah Pastoral Neolithic (SPN) sites are both more geographically widespread – from northern Kenya to northern Tanzania – and more variable in terms of ceramics, obsidian sources, and settlement patterns. It has been suggested that SPN heterogeneity could reflect localized adaptations to increasingly unpredictable rainfall and grazing conditions (Marshall et al., 2011). It must be emphasised that the distinctions among traditions within the SPN remain fuzzy, as do distinctions between these and later Pastoral Iron Age (PIA) traditions, discussed in the following section, which date to c. 1900–1300 yr BP (Lane, 2013a, 2013b).

While the spread of specialized pastoralism is the most distinctive phenomenon of the 3000–1500 yr BP window, it is also spatially restricted: to date, no unambiguous PN settlements have been found near the Indian Ocean coast, for example, nor farther west than the Nyanza area of eastern Lake Victoria. While recent discoveries extend the distribution of the PN southward (Prendergast et al., 2013), there is still no evidence that stone-using herders penetrated into central-southern Tanzania, despite strong genetic and, more debatably, archaeological arguments for connections between eastern and southern African prehistoric herding communities (e.g., Macholdt et al., 2014; Pickrell et al., 2014; Ranciaro et al., 2014; Russell and Lander, 2015; Skoglund et al., 2017).

Given this restricted distribution of early herders, it should be no surprise that interactions amongst people with different subsistence strategies and, presumably, group identities, were a defining characteristic of this era. It is also possible that fluidity in individual and group subsistence strategies, perhaps on a seasonal basis, results in sites that archaeologists interpret as evidence of interaction. Indeed, at the PN site of Prolonged Drift in central Kenya, seasonal pursuit of large migratory mammals, alongside herding, is well documented (Gifford et al., 1980). In the Turkana Basin, two post-Nderit ceramic traditions – Turkwel and Ileret – are associated with pastoralists who also consumed fish, and small sites associated with fisher-foragers have also been documented at this time (Robbins, 1984; Barthelme, 1985). However, dating and additional understandings of these sites remain limited. Turkwel ceramics are also documented from around Lake Baringo (Petek, 2015), where they have recently been dated to c. 1650–1500 yr BP at Oltioki (unpublished data, Nik Petek). In the Victoria Basin, Kanyore ceramics continue to be used until at least 2000 yr BP, and are associated with fishing, hunting, and increasingly, livestock keeping. Two sites – Gogo Falls and Wadh Lang'o – also have substantial Elmenteitan occupations lasting until c. 1700–1500 yr BP, with technological discontinuities in stone tool and pottery manufacture from Kanyore to Elmenteitan levels perhaps marking the arrival of specialized pastoralists from elsewhere. However, unlike their counterparts away from Lake Victoria, the Elmenteitan stock-keeping inhabitants of Gogo Falls and Wadh Lang'o hunted and fished substantially (Marshall and Stewart, 1995; Lane et al., 2007; Prendergast, 2010). While this was initially seen as an adaptation to more closed, tsetse-infested environments, recent isotopic work suggests the presence of open grasslands around Victoria-Nyanza during Elmenteitan occupations c. 2000–1500 yr BP (Chritz et al., 2015). Meanwhile, at rockshelters in the

highlands of Kenya and Tanzania, the presence of domestic fauna alongside LSA lithics and limited numbers of ceramics may indicate temporary occupation of these environments by herders, or perhaps more likely, the incorporation of livestock into forager lifeways. Such zones of interaction are particularly well documented in the Central Rift Valley of Kenya (Ambrose, 1984) and the Eyasi Basin in northern Tanzania (Mehlman, 1989; Prendergast and Mutundu, 2009; Prendergast, 2011).

The spread of specialized pastoralism may have resulted in substantial but localized effects on vegetation and microfaunal communities, as indicated by a number of ecological and ethnoarchaeological studies (e.g., Shahack-Gross et al., 2003, 2004; Simons and Ambrose, 2008; Muchiru et al., 2008, 2009; Weissbrod, 2013; see also Boles and Lane, 2016; Boles, 2017). These studies highlight how pastoralist settlements can shape local ecodynamics – such as soil nutrient redistribution as a product of grazing-corralling cycles – with the implication that, for archaeologists, such effects offer investigative proxies for the ephemeral material residues associated with mobile communities. While methodologies for recognising and interpreting these ecological effects in the deep past are still in development, heterogeneity in soils and vegetation communities has been successfully linked to pastoralism at the PN site of Sugunya in southwestern Kenya, c. 2000 yr BP (Simons and Ambrose, 2008).

This window of time is marked by yet another arrival of food producers, in this case the makers of Urewe ceramics, which appear at sites in lacustrine and riverine environments around the Victoria Basin in Uganda, Tanzania, and Kenya, as well as in more forested and highland areas in Rwanda and Burundi (Desmedt, 1991). The earliest of the Urewe sites appear west of the lake beginning c. 2500 yr BP (e.g., Posnansky, 1969; Van Grunderbeek, 1992; Reid, 1994), reaching the northeastern side (Nyanza) around c. 1800–1500 yr BP (e.g., Leakey et al., 1948; Lane et al., 2006; Ashley, 2010). In Nyanza, Urewe contexts frequently overlie Kanyore and/or Elmenteitan horizons, and contact between foragers, herders, and these newly arrived food producers is hypothesized (Robertshaw, 1991; Lane et al., 2007; Ashley, 2010), with the possible periodic formation of more stable cultural and economic frontiers between them (Lane, 2004). On the west side of Lake Victoria, there is also evidence for some degree of continuity between LSA and Urewe occupations (Reid, 1994). At some Urewe sites, there is evidence for metallurgy (e.g., Childs and Herbert, 2005; Schmidt, 1980; Schmidt and Childs, 1995), and it has been inferred, together with palaeoecological data (see above), that iron production resulted in major changes to vegetation. For example, Giblin et al. (2010) describe a human burial at the site of Kabusanze, Rwanda, wherein finely-crafted iron objects, including jewellery, were found in direct association with Urewe ceramics, also finely-made. The authors speculate that the craft specialisation this indicates may be related to agricultural expansion and food surplus during the early second millennium BP (see also Schoenbrun, 1998).

Even in the absence of evidence for metallurgy, Urewe ceramics are commonly taken as proxies for iron-using farming populations. This is also true of other EIA ceramic traditions, thought to be related to Urewe: Kwale ware (Soper, 1967) is found at sites along the coast and coastal hinterland, occasionally in association with evidence of ironworking; a more poorly-defined variant, Lelesu, is taken as a marker of the EIA in north-central Tanzania (Mehlman, 1989). All of these EIA ceramics are traditionally linked with farming migrants whose origins lie in equatorial west-central Africa, the hypothesized homeland of Bantu languages. Such assertions were made in the absence of rigorous chronological and archaeobotanical evidence. However, it is now recognised that this so-called “Iron Age package” of Bantu languages, along with African cereals and iron technology, was not tightly packed at all, and that the physical migrations of people, and the disseminations of words, ideas, technologies, and crops, would have varied in tempo and scale (for recent linguistic and archaeological assessments, see Grollemund et al., 2015; de Maret, 2013; Crowther et al., 2017).

Archaeobotanical and archaeofaunal data from Early Iron Age sites, in both the Great Lakes region (Lane et al., 2007; Prendergast, 2008; Giblin and Fuller, 2011) and along the coast in Kenya and Tanzania (Pawlowicz, 2011; Crowther et al., 2016a; Crowther et al., 2017), are now helping to disentangle subsistence, material culture, and identity. Unfortunately coastal EIA sites, compared with Middle Iron Age (MIA) sites, discussed below, have poor bone preservation, preventing a full discussion of subsistence strategies. An exception to this is Juani Primary School, where faunal and botanical data point to a strong marine orientation, with occupants reliant on shellfish and fish, with only occasional hunting and no unambiguous evidence of animal husbandry nor farming securely associated with EIA contexts (Crowther et al., 2016a), despite the presence of Kwale ware. In the Victoria Basin, fauna are well preserved at several sites with Urewe ware, and in each case there is little change from the mixed hunting, fishing, and herding strategies that were previously common in this area in association with Kansyore and Elmenteitan ceramics (Lane et al., 2007; Prendergast, 2008). Historical linguistic data further suggest that by the end of this period early Bantu-language speakers settled in the area had developed an integrated farming regime that included yams (*Dioscorea* spp.), oil-palm, a type of bean, and perhaps cowpea and Bambara groundnut (*Vigna subterranea*) among the root crops cultivated, and had also adopted sorghum and pearl millet and perhaps finger millet from neighbouring groups farther north (Schoenbrun, 1993a, 1993b, 1998). The appearance of new terms around 1500 yr BP for ‘field’, ‘to weed’ and ‘to open land by clearing trees’, as well as terms for milking and bleeding cattle, also point to the development of additional agricultural and herding practices associated with an increasing domestication of the landscape (Schoenbrun, 1993a, 1993b).

3.3iv. Archaeological history from 1500 yr BP to present

The past 1500 years in East Africa have been a remarkable time of economic and social change, with a dramatic increase in both the extent and intensity of agriculture, as well as the development of urban centres; the amplification of existing long-distance exchange networks; and the introduction of new actors and items of exchange. These developments have major implications for land-cover change. While mosaics of people reliant upon fishing, foraging, herding, and farming define this era (Kusimba and Kusimba, 2005) - and to some extent continue to the present day - there is no doubt that over time, foraging populations shrank and agropastoral populations expanded. Environmental change has been a major driver of population movements within the past half-millennium, bringing new pastoral groups (such as the forebears of the Maasai) to the region and thus shaping ecological and social dynamics at the local level. During the last few centuries and particularly during the colonial era, resource extraction, the trafficking of enslaved people, agricultural commercialization, and infrastructure development were all important drivers of land-cover change and, more broadly, of long-term environmental transformation.

Fishing remains a common strategy during the last two millennia BP, as seen at Turkana Basin sites with Turkwel ceramics like Lopoy and Apeget (Robbins, 1980, 1984), and, as noted above, at Victoria Basin sites with Urewe ceramics like Wadh Lang'o and Usenge 3 (Lane et al., 2007; Prendergast, 2008). In all of these sites, faunal remains attest to mixed herding-hunting-fishing economies, with herding varying widely in importance. While iron-using agropastoralists extended across much of East Africa during the MIA (c. 1300–900 yr BP), the arid Turkana Basin appears to have been largely unaffected by the spread of both iron working and farming, and today the economic mainstays remain dry-lands mobile pastoralism (including camel pastoralism) and fishing.

Around the Lake Victoria Basin, iron-working communities became both numerous and intensive. Ultimately, in some areas these developed into increasingly complex societies and eventually states, as seen in Buganda, Rwanda, and Buhaya (Berger, 1981; Reid, 1994/1995, 1996, 2013; Robertshaw, 1997; Robertshaw and Taylor, 2000; Schoenbrun, 1998). Distinct changes occur in the archaeological record

to the west of Lake Victoria from around 1000 yr BP. These include the appearance of new ceramic styles, characterised by a preference for various kinds of roulette decoration along with changes in vessel form and size (Ashley, 2010), the rapid spread of which may even be indicative of the expansion and intensification of trade and exchange around Lake Victoria (Reid, 2013). Historical linguistic data point to a virtual ‘explosion’ of new terms associated with banana cultivation around the same times as these material developments, and also in the terminologies of herding and pastoralism (Schoenbrun, 1998), pointing to further elaboration and sophistication of food production strategies in the Great Lakes region. There is material evidence also for growing specialisation, including salt production at Kibiro on the eastern shores of Lake Albert (Connah, 1996; 1997), and in cattle herding at sites such as Ntuusi (also spelled Ntusi), occupied c. 950–450 yr BP, situated in Mawogola, south-western Uganda (Reid, 1994/1995).

Extending over c. 100 ha, but with deposits rarely > 20 cm in depth apart from two large mounds of occupation debris, Ntuusi was the focal point in the Mawogola landscape for almost five hundred years, and can be seen as being linked to an extensive network of smaller sites in the vicinity (Reid, 1994/1995). Faunal remains from Ntuusi indicate a focus on cattle herding from the initial establishment of the site onwards. Reconstructed mortality profiles indicate that most livestock were slaughtered at an extremely young age—a practice that would have been possible only with the existence of large herds (Reid, 1996, 2013). Storage pits, numerous grinding stones, some reaping knives and two clusters of carbonised sorghum attest to the importance of agriculture, which likely also included banana plantations, alongside cattle. The presence of a combination of working debris and finished ivory objects also highlights the significance of elephant hunting locally (Reid, 2015).

Based on the material evidence from Ntuusi, establishment of the site appears to mark the beginnings of a ranked society and socio-political complexity in this part of East Africa, laying a base from which various kingdoms later developed. A feature of some of the immediate political successors of Ntuusi was the construction of a series of deep encircling trenches around the central part of the occupation area, extending over several kilometres at some sites, as exemplified at Bigo bya Mugenyi (13 km north of Ntuusi on the Katonga River), and at the site of Munsa in the more forested areas of western Uganda. Although massive, the configuration of these earthworks does not suggest they were principally defensive in nature, and they may well have served more political and symbolic roles associated with marking centres of power and ritual authority (Robertshaw, 2010; Reid, 2013). Although cattle dominate the faunal remains recovered from excavations at both Munsa and Bigo, the presence of several large grain storage pits at Munsa emphasise the importance of crop cultivation for at least some of these capital sites (Robertshaw, 1997), alongside the maintenance of banana plantations. The scale of the earthworks also point to an ability to pool the labour of fairly large groups and sufficient surplus production to feed this workforce, with likely environmental consequences. As noted above, for example, the pollen record and other environmental proxies for the period point to widespread forest disturbance and increased burning associated with this settlement phase (Taylor et al., 2000; Leju et al., 2005).

On current evidence, the earthwork sites appear to have been abandoned around 300–250 yr BP. Archaeological survey data also suggest a change from nucleated toward more dispersed settlement patterns at the village and homestead levels of the settlement hierarchy (Robertshaw, 1994). New capitals for the kingdoms of Bunyoro, Nkore and Buganda emerged, and reports compiled by the first Europeans to visit the Great Lakes kingdoms in the nineteenth century indicate that their capitals were sizeable settlements housing several thousand inhabitants, and structured by distinct spatial divisions based on class/occupation. However, many of these settlements were fairly short-lived, often occupied for less than a decade (Reid, 2013). Coupled with the preference for using wood, mud and thatch for house construction, and

the damp, warm soils of the region, archaeological preservation, especially of the animal and plant remains that can provide information about insights into food production strategies and land use, is often poor. At present, only limited archaeological data are available concerning these capitals, with just two, the Nkore capital at Bweyore and the Mpororo capital of Ryamurari, both occupied c. 350–250 yr BP, having been subjected to detailed archaeological investigation (Posnansky, 1969; Reid, 2013). These data are supplemented by a larger body of ethnohistorical information from linguistic, oral and documentary sources attesting to food-producing economies based on banana plantations and cattle herding (Schoenbrun, 1998) supplemented by arable cultivation of African cereal crops (Reid and Young, 2000). These same sources indicate continuing economic diversification, including specialised iron (Humphris et al., 2009) and salt (Connah, 1996) production and kaolinite mining (D.A.M. Reid, 2003), and a flourishing regional exchange system, much of it by boat across and around Lake Victoria (Kenny, 1979). This period also witnessed growing political complexity, although not necessarily centralisation (R. Reid, 2003; Robertshaw, 2010), and by c. 200 yr BP aggressive military expansion of the more powerful states, especially Buganda (Reid, 2007), alongside greater religious and symbolic elaboration of kingship (Sassoon, 1983; Reid and MacLean, 1995). Various forms of enslavement, mostly for either internal domestic or agricultural purposes initially, but later also for external trade, are also well-attested across the interlacustrine region in both the oral and documentary historical sources for this period (Médard and Doyle, 2007).

On the eastern side of Lake Victoria, the archaeological characteristics of MIA farming and herding communities are poorly documented. Scattered traces are known from archaeological surveys around the lake margins and along the major rivers draining into the lake (e.g. Robertshaw, 1991; Lane et al., 2006), and from material recovered from the upper horizons of excavated PN and EIA sites, such as Gogo Falls and Wadh Lang'o. Oral histories of the Luo, who are the main inhabitants of this area today and speakers of a Western Nilotic language, suggest that relatively small groups of clan-based, mixed farming-herding-fishing communities established themselves around the lake margins from around 560 yr BP in a series of phases, moving in from areas farther north and west (Ogot, 1967; Cohen, 1983). According to these histories, settlement was initially around Got Ramogi Hill and Yala Swamp, before expanding across the Uyoma peninsula and southwards around the Winam Gulf and into what is now Migori County, SW Kenya by c. 300–200 yr BP (Ogot, 1967; Ochieng', 1974; Herring, 1979). A single archaeological site identified in these oral histories and containing roulette-decorated ceramics similar in form and design to ethnographically documented Luo pottery has been excavated. Known as Usare 1, the site comprises a series of three low occupation mounds with shell-midden deposits close to the current lake edge at the southern end of Asembo Bay. Dated to c. 430–300 BP, faunal remains recovered from the site suggest a mixed fishing and cattle-based herding subsistence economy (Lane et al., 2006). Subsequently, the practice of enclosing individual homesteads and larger villages within earthen bank-and-ditch enclosures (*gunda buche* in the Dholuo language) became common in the areas north of the Winam Gulf, with over 60 examples now known (Odede, 2008) and likely many more have been destroyed by farming since the early twentieth century. Only one of these, Lwak, has been excavated. Finds from the site suggest a mixed agropastoral economy, with a similar range of crops (sorghum, millet, beans, maize) and livestock (cattle, sheep, goats, chicken) as described by the first European visitors to this area of western Kenya (e.g. Johnston, 1902). Intriguingly, the ceramics from the lowest levels of the ditches exhibit typological similarities to MIA pottery from the area, lending support to certain clan histories that suggest some enclosures were founded by the Bantu-language speakers the Luo encountered as they moved into the area.

South of the Winam Gulf, enclosures were typically built using drystone walling (*ohinga*, pl. *ohingini*, in Dholuo). The larger and better

preserved of these contain one or more stone-walled livestock enclosure with traces of house-platforms and grain-bin foundations arranged concentrically around the inside wall (Lofgren, 1967). Some have drystone walls and driveways arranged in a spoke-like fashion around the main enclosure, creating a series of radiating agricultural plots. Stone terracing is also evident at some sites. Over 135 of these stone-walled enclosures are known. Nearest Neighbour and Cluster Analyses of their distribution and topographic setting, indicate a preference for hill-top and upper slope locations close (typically ≤ 3 km) to a permanent water source (Onjala, 2003). They also tend to occur in distinct clusters, with the highest density around the site of Thimlich Ohinga, and elsewhere in Macalder district, Migori County. Thimlich Ohinga is the largest and best preserved example, dated to c. 280–110 yr BP (Wandibba, 1986). Faunal remains from this site attest to the herding of cattle and small stock, with fish and wild game supplementing local diets. Grain-bin foundations, and upper and lower grinding stones indicate the importance of crop cultivation. By the late nineteenth century, quite a diverse range of crops were being grown. Johnston (1902, 787), for example, noted that the Luo cultivated sorghum, sweet potatoes, peas, eleusine, pumpkins, tobacco and hemp; there are also references to sesame, green gram, beans and speckled maize in some of the other documentary and oral sources. There is no supporting archaeobotanical evidence from these sites at present, however.

In the Rift Valley of Kenya and Tanzania, evidence of early farming is nearly absent, other than at the Pastoral Iron Age (PIA) site of Deloraine, c. 1200 yr BP. This site is remarkable for an apparently unique ceramic tradition as well as having, until recently, one of the few direct signs of agriculture in the form of a single finger millet grain (Ambrose, 1984; Harlan, 1992; Sutton, 1993). This and neighbouring PIA sites, such as Hyrax Hill (Leakey and Owen, 1945; Sutton, 1987; Kyule, 1997) are interpreted as possibly emerging from later Elmenteitan communities, and later gave rise to a distinct form of permanent settlements known in the literature as “Sirikwa holes” or “hollows”, after the depressions formed at their centre. The distribution of Sirikwa sites covered much of the Western Highlands of Kenya, extending into the central part of the Eastern Rift Valley as far as Lake Nakuru, with over 200 individual Sirikwa sites documented that together span the period from c. 750–150 BP (Sutton 1973; Sutton, 1987; Davies, 2013). Excavations have shown that Sirikwa sites comprised one or more individual homestead consisting of a central livestock enclosure around which were grouped a series of houses and other structures (interpreted by some as guard huts), with a single entrance into the enclosure that could be closed off (presumably at night and during times of conflict to protect the livestock and occupants from animal and human predators). The food-producing economy of these sites varied; in the drier areas of the Rift Valley, such as at Hyrax Hill and Lanet, more emphasis was placed on livestock herding, whereas at sites in the wetter Western Highlands, such as Chemagel, more emphasis may have been placed on crop production (Posnansky, 1957; Sutton, 1993; Kyule, 1997), although much more systematic archaeobotanical, bioarchaeological and geoarchaeological research is needed at these sites to determine the range of crops exploited, the relative balance of herding versus cultivation and the overall nature of land use around these sites.

As noted above, in the central Eastern Rift Valley, traces of late PN Turkwell activity are quite widespread around the southern end of Lake Baringo. In contrast, diagnostic traces of PIA communities are relatively scarce, limited to inconclusive remains of settlement activity and to a few scatters of Lanet pottery (c. 1050–250 yr BP) and a single occurrence of Kisima ceramic (c. 500–250 yr BP; Petek, 2015). Wetter than present conditions between c. 750–150 yr BP are suggested by various palaeoenvironmental records for the region, and it is possible that the consequent decrease in C_4 grasses and an increase in woody and shrubby vegetation may have encouraged an expansion of tsetse flies, reducing the overall suitability of the areas around Lakes Baringo and Bogoria for livestock herding. A major dry spell centred around 350 yr BP resulted in a significant reduction in the size of Lake Baringo (Kiage

and Liu, 2009), and is likely also to have had a significant impact on local livelihoods, possibly encouraging settlement abandonment and a shift to hunting and gathering (Petek and Lane, 2017). This was followed by another major drought of a sub-continental scale around 150 yr BP (Bessems et al., 2008), causing major socio-ethnic disruptions resulting in the formation of new ethnic groupings and both an animal and human depopulation of the Baringo basin until c. 120 yr BP (Anderson, 2016; Kiage and Liu, 2009). One of the new ethnic communities were the Il Chamus who, after the conditions ameliorated, practiced large scale irrigation farming on the lowlands south of Lake Baringo, though stock-keeping and hunting remained part of the economy (Anderson, 2002; Petek and Lane, 2017). They lived in densely settled villages with activities concentrated around nearby well-watered areas, expanding and intensifying their irrigation system between 130 and 70 yr BP due to the increasing population resulting from immigrant destitute pastoralists from the Central Kenyan Rift and Laikipia and due to the arrival and intensification of the caravan trade. The surrounding Baringo-Bogoria lowlands were seasonally utilised by various pastoralist groups such as Il Doijo and several Maasai sections (Anderson, 2002; Petek and Lane, 2017).

To the west of Baringo the end of the Sirikwa society appears to have led to the formation of what are now two distinct communities - the Pokot and Marakwet - in the Kerio Valley and northern Cherangani. Both communities appear to have first commenced land clearance and begun using irrigation around 250 yr BP, and both formerly used pottery styles suggesting a cultural affiliation with Sirikwa traditions (Davies and Moore, 2016). Between c. 200–150 yr BP the ancestors of the modern-day Pokot split into an agricultural and a pastoral faction, whereafter the agricultural Pokot expanded southwards from the drier lowlands to the well-watered highlands in the Cherangani Hills (Davies, 2008), with the pastoral sections becoming more mobile and eventually employing rangelands that extended eastwards into Baringo and into what is now Uganda (Davies and Moore, 2016). Irrigation and the construction of terraces for homesteads and agricultural fields is a feature of crop production among the Marakwet and agricultural Pokot, but prior to c. 100 BP both communities had very dispersed settlement patterns based on individual households, and agricultural plots associated with these households are likely to have been relatively short-lived (Davies, 2008); a point that is essential in reconstructions of historical land cover since even 'intensive' systems of agricultural production need not lead to extensive or permanent land clearances. These agricultural communities in the Rift Valley occupied relatively niche locations, growing mainly finger millet, sorghum, leafy greens, and legumes (Davies and Moore, 2016; Petek and Lane, 2017). As the agricultural Pokot were moving south, the faction that would become the pastoral Pokot received a significant influx of immigrants from western Turkana and Karamoja in Uganda, likely due to the previously mentioned sub-continental drought. Though oral history records that most of the newcomers and the Pokot ancestors mainly practiced mixed subsistence economies, the community reorganised itself around a specialised pastoral lifestyle and a society centred around cattle, and rapidly expanded to exploit the patchily spread resources from Karamoja to the Leroghi Plateau and north of Lake Baringo by about 100 yr BP (Anderson and Bollig, 2016; Bollig, 2016; Bollig and Österle, 2013). About 50 yr BP, Il Chamus and Tugen would also become predominantly pastoral communities.

Vegetation conditions on the adjacent Laikipia Plateau to the east may have been more favourable for pastoralism over much of this period. Archaeological surveys and excavations indicate a significantly higher density of PIA surface scatters relative to PN remains (Siiriäinen, 1984; Causey, 2010; Lane, 2011), suggesting an increase in settlement across the Laikipia Plateau and the Ewaso Basin more generally. Charcoal and fungal spore records recovered from different palaeoenvironmental sampling sites on Laikipia Plateau point to increased burning and higher herbivore densities from c. 1650–650 yr BP, corresponding with a steady replacement of Afrotropical vegetation by

woodland and bushland taxa (including *Capparis*, acacia, and *Grewia*) in the pollen record (Taylor et al., 2005; Muiruri, 2008), indicative of an expansion of open, disturbed savannah habitats typically associated with pastoral land use. Only a handful of sites for this period have been test-excavated. These include two large pastoral encampments: the Maasai Plains site near Loitigon Vlei in the northwestern part of the Plateau, occupied around 635–330 yr BP, and Maili Sita (also spelled Mili Sita) in the Lolldaiga Hills in the southeast, occupied c. 280–100 yr BP (Lane, 2011; Boles and Lane, 2016). Faunal assemblages from both sites indicate an emphasis on raising cattle and to a lesser extent sheep and goats, supplemented by hunting wild game. There is evidence also from different parts of the Ewaso Basin for localised iron smelting (Larick, 1986; Iles and Lane, 2015) using titanium-rich magnetite soils exposed through erosion, and indeed it may be significant in terms of ecological impact that the smelting techniques used were comparatively fuel-efficient (Iles and Martín-Torres, 2009). Hunter-gatherers also continued to exploit this landscape, although competition for land and other resources suggests that these groups may have been increasingly encapsulated from c. 300 yr BP (Herren, 1987). Oral historical sources nevertheless indicate close interaction between some hunter-forager and pastoralist communities, with certain hunter-forager groups (or clans within groups) likely providing honey and pottery (Bernsten, 1976; Grillo, 2014) and perhaps also elephant ivory in return for livestock and other pastoralist products. Faunal remains recovered from excavations at Shulumai Rockshelter in the Mukogodo Hills suggest a hunting strategy oriented toward exploiting small species such as hyrax, dik-dik, and bushpig, supplemented by small numbers of domestic cattle and sheep or goats, with the eventual adoption of fully pastoral livelihoods and identity around 200 yr BP (Mutundu, 1999; Cronk, 2004).

Archaeological surveys and excavations in the Mara plains in southwest Kenya also attest to the dominance of pastoralism in this area (Robertshaw, 1990), despite the continuing human and livestock disease threats posed by tsetse fly. Changes in pottery styles link the area to PIA communities farther north, while iron smelting was adopted by some sections of these communities (Siiriäinen et al., 2009). In the Lake Simbi area, western Kenya, pollen and other palaeoenvironmental data point to the practice of low-intensity, slash-and-burn subsistence agriculture, probably including some small-scale cattle herding, eventually giving rise to a mosaic landscape of small farm fields, pasture and regenerating natural vegetation (Mworia-Maitima, 1997; Lamb et al., 2003; Colombaroli et al., 2016). In southeastern Kenya, around the Amboseli Basin and Taita-Tsavo area (Kusimba and Kusimba, 2005; Kusimba et al., 2005), similar mixed mosaics of farmers, herders and hunter-gatherers existed, and were linked through systems of reciprocal exchange and exploitation of different ecological niches and economic specialisation. Unusually, however, no evidence of iron production has been recovered in Amboseli despite extensive surveys (Foley, 1980; Anna Shoemaker, unpublished data). As international demand for elephant ivory grew, initially around 450 yr BP from China and India, and subsequently from Europe and North America especially after c. 110 yr BP (Beachey, 1967), the Amboseli area may have experienced significant reduction in elephant numbers, although at present it is difficult to discern the scale and ecological impact of these extractions. A parallel increase in the demand for slaves to feed Red Sea and Indian Ocean markets over the same period likely also contributed to shifts in settlement locations to more defensible higher ground, as documented around Mount Kasiagau, Tsavo, and also probably caused disruption to local food-production economies (Kusimba, 2004).

The extraction of slaves and ivory from inland areas like Amboseli relied on the ability to provision trade caravans, and this was evidently achieved in northern Tanzania by skirting the well-watered highlands of the Usambara and Pare Mountains, Mount Meru and Kilimanjaro. Human occupation of these highlands has a long history, and although archaeological data is patchy it would appear – as one might expect – that farming communities favoured the comparatively wet southern

and eastern slopes and foothills of these mountains. A variety of sources attest to farming on the southern and eastern slopes from at least 1000 BP. These include multiple finds of Iron Age pottery types (e.g. [Odner, 1971b](#)) that are commonly found elsewhere in association with agriculture (first Kwale ware and then Maore Ware from c. 1300 BP), as well as historical linguistic and oral historical evidence suggesting occupation of Kilimanjaro in the early first millennium BP by the Maa-speaking Ongamo, who grew finger millet and sorghum, and raised livestock ([Nurse, 1979](#); [Ehret, 1984](#)). However, on the north-western slopes of the mountain finds of grinding-stones, stone rings (potentially used as digging stick weights) and Kwale and Maore ceramics in lesser amounts also provide indirect evidence for farming and iron working communities going back as far as two millennia ([Fosbrooke and Sassoon, 1965](#); [Mturi, 1986](#); [Odner, 1971b](#)), though the area may have been primarily used for grazing. The date by which bananas were introduced into these highlands is still unknown, but [de Langhe et al. \(1995\)](#) used the number of species variants now farmed on Kilimanjaro and the adjacent Pare Mountains to estimate local use of the crop since at least 1000 BP, while [Montlahuc and Philippon \(2006 page 63, citing Rossel, 1998\)](#) argue that the crops could not have been introduced until the area became incorporated into long-distance trade networks with the Indian Ocean and beyond after c. 1250 BP. The onset of soil erosion in the North Pare highlands from the early second millennium BP can, however, be plausibly linked to clearance of forested land for agriculture ([Heckmann, 2011](#)), and there is no reason to believe that similar small scale clearances for shifting agriculture were not also taking place in the other highland areas in the Eastern Arc Mountains. Increases in the scale and intensity of soil erosion in North Pare in the early first millennium BP ([Heckmann, 2011](#)) correlates well with radiocarbon dates on some iron working furnaces on the lower footslopes of the mountains ([Odner, 1971a](#)), while the commencement of more severe soil erosion from c. 350 BP coincides with radiocarbon dates from a larger number of iron smelting and smithing furnaces from Pare, and with oral historical evidence from both Pare and Kilimanjaro suggesting that settlements and irrigation structures were already established at this time (see [Stump and Tagseth, 2009](#) and references therein). Oral historical sources – in some cases with support from archaeological data – strongly suggest that similar processes were taking place at about the same time in South Pare ([Sheridan, 2002](#)), Usambara (e.g. [Feierman, 1990](#)), and Meru ([Spear, 1993](#)); for an overview of which see [Stump and Tagseth \(2009\)](#). In very general terms then, land use on the well-watered slopes of the highlands of northern Tanzania can be characterised as being based on the cultivation of grains and bananas since c. 350 BP, but it is perhaps not until the establishment of some degree of local political centralisation and the intensification of the caravan trade from c. 110 BP that the landscape started to resemble that of open fields and tree-shaded banana plantations evidenced today.

Farther to the south in Tanzania, elaborate terrace and irrigation systems are observed in the Manyara Basin and at the base of the Crater Highlands, most notably at the site of Engaruka (e.g. [Sutton 1984](#); [Stump, 2006](#); [Westerberg et al., 2010](#)). Radiocarbon determinations indicate that parts of the 2000 ha of agricultural fields and associated settlements at Engaruka were in place by 650 yr BP (summarised in [Westerberg et al., 2010](#)), while historical sources demonstrate that the site was entirely abandoned by the 70 BP, and by inference abandonment probably occurred – likely gradually rather than by mass migration – in the period of c. 200–150 BP ([Sutton, 2004](#)). The construction of the field system and its attendant network of irrigation channels and canals was elaborate, with large parts built by capturing sediments eroded off adjacent high ground ([Stump, 2006](#); [Lang and Stump, 2017](#)). This suggests severe soil erosion occurred in adjacent areas, with removal of vegetation being the likely trigger, though the extent of this removal and whether it had a human or climatic origin is the subject of ongoing work. Attempts have been made to relate the development of the field and irrigation system to palaeoclimatic variability interpreted from proxy evidence in the sediments from the nearby Lake Emakat

([Westerberg et al., 2010](#)). Taken together the combined evidence from the site indicates an emphasis on cereals (Sorghum and Pearl millet), but the quantities and age profiles of animal bones recovered from excavations of the settlement areas (e.g. [Robertshaw, 1986](#)) suggests that some cattle and small stock were kept on or near the site, which in turn suggests the economy required access to grasslands outside the more intensively cultivated area.

Although in many cases not well dated, the use of irrigation and/or agricultural terracing was not restricted to the communities at Engaruka and those and in the highlands of northern Tanzania and the Kerio valley of Kenya; gazetteers and brief discussions of which are presented for this region and beyond in [Adams and Anderson \(1988\)](#), [Grove and Sutton \(1989\)](#) and [Widgren \(2017, in press\)](#). Most of these are small in scale and/or of low intensity until 150 BP or later, but are nevertheless significant for mapping both land use and land cover, since it now seems increasingly clear that an economic focus on relatively intensive crop production required access to broader pastoralist resources, and indeed that highly specialised forms of pastoralism required regular contact with settled agriculturalists (e.g. [Håkansson and Widgren, 2007](#)).

On the coast and in the coastal hinterland, a large number of sites date to the MIA, though some of these – such as the above mentioned Juani Primary School site ([Crowther et al., 2016a](#)), and Mgombani in the hinterland ([Helm, 2000](#)) – also had substantial EIA occupations. At these and other MIA sites such as Fukuchani and Unguja Ukuu on Zanzibar, there is clear archaeobotanical evidence for farming, mainly of African cereals such as sorghum, pearl millet, and finger millet, as well as the cowpea ([Crowther et al., 2017](#)). However faunal exploitation is highly variable from one site to the next, as recently reviewed by [Quintana Morales and Prendergast \(2017\)](#). For example, faunal remains from the Zanzibar sites point to a continuing marine orientation, with fish forming a key part of the diet, followed by hunting of terrestrial game, especially at Fukuchani; at Unguja Ukuu, management of caprines and chickens is a key part of the economy, alongside wild terrestrial and marine fauna ([Prendergast et al., 2017](#)). In contemporaneous contexts at Shanga, in the Lamu archipelago, domestic animals form the bulk of the diet ([Mudida and Horton, 1996](#)). Systematic archaeological surveys of several areas, including the area between Mombasa northward to Mida Creek, on the central Kenya coast ([Helm, 2000](#)), along the lower Pangani valley, NE Tanzania ([Walz, 2010](#)), around Kilwa ([Wynne-Jones, 2007](#)) and Mikindani ([Pawlowicz, 2011](#)) in southern Tanzania, and on Pemba ([Fleisher, 2003](#); [Kessey, 2003](#)) all indicate a trend toward an increasing density of rural settlements and the filling out of the landscape, likely due to demographic growth.

During the MIA and continuing into the Later Iron Age (from c. 900 yr BP), urban centres (commonly known as stone towns, an allusion to coral-rag architecture) develop along the coast and islands, where they served as important entrepôts for the exchange of goods from the interior to the coast, and from the coast and islands to the broader Indian Ocean maritime world ([Horton and Middleton, 2001](#); [Boivin et al., 2013](#); [Wynne-Jones, 2016](#)). This trade is evident in the arrival of new crops, including Asian rice, mung bean (*Vigna radiata*), and coconut (*Cocos nucifera*). While Asian crops appear during the MIA at sites such as Unguja Ukuu, Zanzibar ([Crowther et al., 2016b](#); [Crowther et al., 2017](#)), Mafia ([Crowther et al., 2014](#)) and Tumbe on Pemba ([Walshaw, 2010](#)), they – and especially rice – become more abundant after c. 900 yr BP, as evidenced, for example, at Chwaka on Pemba ([Walshaw, 2010](#), [Walshaw, 2015](#)). Apart from this localised shift towards rice agriculture, sites remain mostly dependent on local crops, and on small-scale agriculture and household-level production. This suggests a relatively circumscribed area of farmed land around the towns, which would account for the regionality of subsistence practices in coastal towns, drawing on local crop regimes and practices ([Walshaw, 2015](#)).

Settlement growth is consistent, although not evenly spread, along the coastal strip throughout the MIA and LIA. From c. 900–400 yr BP

many hundreds of sites with coral architecture are known from Somalia to Mozambique. Many were very small, and their ‘urban’ status might be a matter of debate, but overall the settlement pattern reflects a consistent trend towards permanent, settled, life along this strip. There are certain centres of population, notably on the offshore islands and archipelagos of the coast (Lamu, Zanzibar, Mafia, Kilwa). Here, agricultural land beyond the town (and on the mainland opposite coastal island groups) would have been drawn into cultivation; although archaeological evidence for this is slight, the agricultural hinterland of coastal settlement is well documented historically and may have been based on a slave economy (Vernet, 2015). Overall, this would have contributed to a transformation of the coastal strip, with the large-scale clearance of coastal forests and increasingly dense settlement as the LIA proceeded. As urban centres developed, faunal evidence for increasing ratios of domestic stock and chickens point to the intensification of food production within the towns (reviewed by Quintana Morales and Prendergast, 2017), but also perhaps to the development of regional procurement networks. Specialized fishing technologies are employed to catch larger and more dangerous prey, including sharks, in open waters (Quintana Morales, 2013) as a more explicitly maritime socio-cultural orientation also emerged (Fleisher et al., 2015).

The relationship between this coastal urban development and interior regions of East Africa remains poorly understood, particularly with regard to economic intensification or changes in land-use and labour relations (Lane, 2010, 2014). A handful of studies have explored the inland networks to which coastal towns were connected and a variety of relationships of trade and production have been documented. Yet all have demonstrated continuity of, regional population and subsistence practices. The Tana Valley of northern Kenya (Abungu and Muturo, 1993), the Pangani Valley of northern Tanzania (Walz, 2010), and the deep hinterland of Mikindani in southern Tanzania (Pawlowicz, 2012), were all occupied throughout the MIA and LIA by village communities practicing small-scale agriculture; each was connected with the urban development of the coast periodically or continuously, but without significant effect on subsistence practices. In southern Kenya research has found evidence for foragers and agriculturalists connected with the coast in a ‘mosaic’ of peoples and practices (Kusimba et al., 2005).

In 1498 CE, the Portuguese explorer Vasco da Gama's small flotilla entered the Indian Ocean and sailed up the East African coast before crossing to India (Russell-Wood, 1998). This event ushered in a period of coastal domination, and yet along many parts of the East African coast the presence of the Portuguese would have been hardly noted, if at all, by the vast majority of the local population. Other, non-Western, non-African powers and actors played active roles in shaping the economies and social dynamics of the East African coast over the next 500 years – including the Ottoman Empire in the sixteenth and seventeenth centuries, followed by Omani Sultanates, and various Indian merchants and financiers who had long been engaged in trade along the East African seaboard (Pearson, 2005; Alpers, 2013). The material traces of a Portuguese presence on the East African coast are also quite limited. On Zanzibar, trading posts (*feitorias*), that were simultaneously warehouses, markets and customs offices, were established during the sixteenth century at Mvuleni, Fukuchani, and at the Gereza in Stone Town, where a cruciform church was built. Another church survives almost intact in Malindi, which was closely allied to the Portuguese, who also established an unfortified *feitoria* here and erected a stone cross to commemorate their landfall (Finneran, 2002). Their main settlement, however, was on Mombasa Island, which became their centre of political authority and commercial operations after 1590 CE (Kirkman, 1974; McConkey and McErlean, 2007). Unfortunately, little is known archaeologically about either the colony settlement known as ‘Gavana’ that the Portuguese established just north of Fort Jesus, or the local town of Tuaca, on the south-western tip of the island, which was occupied from at least the twelfth century and is believed to have been abandoned in the sixteenth century after the arrival of the Portuguese.

The establishment of small Portuguese enclaves may well have further encouraged a degree of commoditization of food production in coastal areas so as to supply growing urban communities and passing ships. However, the available Arab and early modern European sources indicate that surplus food production for regional exchange was already established prior to the arrival of the Portuguese. Perhaps the most significant, albeit long-drawn out, consequence of the establishment of a Portuguese presence on the east African coast (unlike in Mozambique, where their influence on local economies was rather more substantial), was the introduction of North American domesticates, particularly maize and tobacco, but also other crops such as potatoes (*Solanum tuberosum*) and sweet potatoes (*Ipomoea batatas*), although the timing, rate and directions of their spread in East Africa remains under-researched. Even less is known regarding the introduction of New World diseases, especially syphilis and polio, among local populations, although their impacts were far less than the well-documented devastation caused by the introduction of Old World diseases into the Americas.

The assumption of Omani political and economic control over the coast strip from c. 1740 CE until the establishment of European colonial rule over the region, seems to have had a greater impact on land use in the coast region. The combined consequences of an increased demand for supplies of elephant ivory and slaves (Beachey, 1967; Sheriff, 1987) seem also to have created a more profound shift in interior landscapes. The most obvious material traces of Omani authority comprise a number of forts constructed at strategic locations on the coast and offshore islands and their modifications to pre-existing Portuguese forts (Pradines, 2004). In terms of land use, a significant change came with the development of plantation agriculture, notably for cloves in the Zanzibar archipelago (Croucher, 2014) and sugar on the mainland, with associated transformations in the nature and extent of slavery and slave raiding (Kusimba, 2004, 2014; Lane, 2013b) from the middle of the nineteenth century onwards. A further and related factor was the growth and transformation of caravan trade around this time, supplying increased demand for elephant ivory in Europe and North America (Coutu et al., 2016). The consequences of this trade were enormous, and the effects on elephant populations and ecologies have been widely discussed. Thorbahn (1979) and Håkansson (2004), for example, charted how the increase in ivory trade would have transformed interior landscapes as elephant stocks on the coast dwindled and traders travelled farther inland. To some extent this has been confirmed by archaeological analysis of historical ivories, which suggest an absence of coastal elephants (Coutu et al., 2016). As elephant populations themselves have profound effects on ecologies, this could have led to an opening up of woodland across a large swathe of East Africa and might, in turn, have led to changes in agricultural practice as disease threats posed by the spread of tsetse fly intensified (Giblin, 1990; Lane, 2010).

The caravan trade itself created new landscape regimes, as areas like the Lake Baringo region were turned over to crops to supply the caravan trade, by the Il Chamus group who has previously had a pastoralist economy (Anderson, 2002; Petek and Lane, 2017). Historical records also document an intensification of agricultural extraction around the newly created centres built along Tanzanian caravan routes, such as Tabora or Ujiji, based largely on a slave economy (Rockel, 2006). Yet the few archaeological studies that have explored these regions have also highlighted continuity (Wynne-Jones, 2010; Biginagwa, 2012). For example, caravan halts in the Pangani Valley have revealed evidence for continuity in local subsistence practices, based on a mixed economy of cattle, hunted fauna, and fishing, despite a growing engagement with coastal trade. The local Zigua communities do seem, however, to have been farming maize (Biginagwa, 2009).

4. Environmental-human interconnections: linking environmental and cultural variability

Humans have long distinguished themselves by using tools and

technologies to shape East Africa's ecosystems so that today, like many places in the world, the landscapes of East Africa are imprinted with a legacy of past anthropogenic activity. There are numerous challenges to investigating the interaction between environmental and cultural change. One of the key challenges is apparent when we plot the palaeoecological and the archaeological sites together across Eastern Africa; we can see there is a large disconnect in the location of these (Figs. 15 and 16). Indeed, there are only a few sites where the palaeoecological and the archaeological insights are from the same location. Most notable where there is coeval insights from the same location is Munsu in Uganda (Lejju et al., 2005, 2006): this site has yielded interesting insights into changing land use and the character of these including cultural transitions relating to crop types used, forest clearance methods employed, particularly the use of fire, and how the timing of some of these transitions appear to be synchronous with rapid phases of environmental change (Lejju et al., 2006; Robertshaw et al., 2004). However, this site has also attracted considerable controversy regarding very early evidence of the possible presence of banana (Fuller et al., 2011), particularly within the archaeological community (Fuller and

Boivin, 2009; Neumann and Hildebrand, 2009). Other locations where palaeoecological and archaeological sites have been studied together have provided great insights, but are more diffuse. This is particularly well exemplified from the Lake Turkana catchment where the changing nature of the lake as it responded to environmental change has impacted directly on the cultural use of the catchment. For example, extensive lowering of lake levels during the mid- to late Holocene exposed large previously inundated lake deposits (Garcin et al., 2012) that supported rich pasture and provided a conduit for the movement of pastoral communities into the East African region (Gifford-Gonzalez, 1998). A further example where this linkage has shown promise comes from Laikipia, where cores taken from the Loitigon Vlei floodplain were considered with respect to new and existing archaeological and historical data, including investigation of the nearby Maasai Plains archaeological site (Taylor et al., 2005). The study linked vegetation change and evidence of burning during the last millennium to pastoralist landscape modification with the aim of extending pasture and epizootic control, and suggested that prolonged spells of aridity might have fostered the expansion of stock-based production in the region.

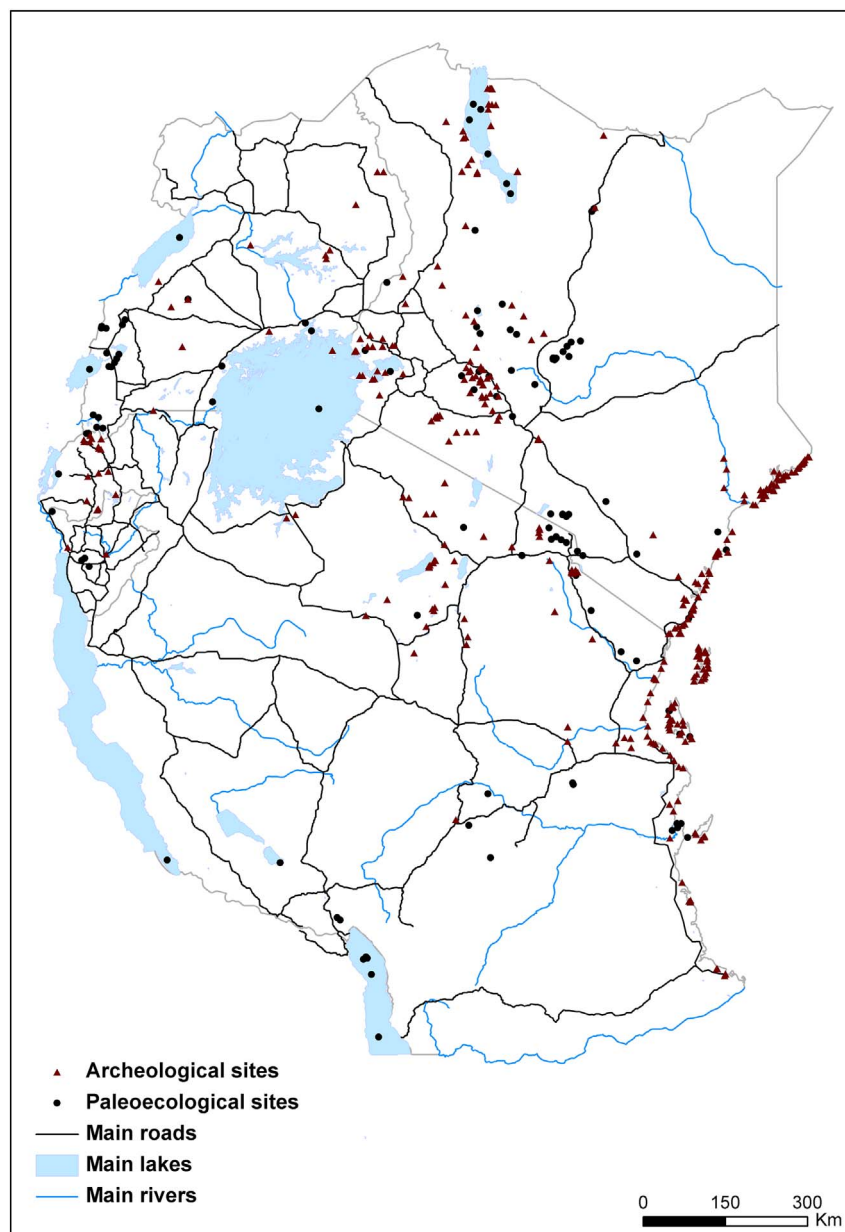


Fig. 15. Plot of Palaeoecological and Archaeological sites in the study area and the main roads network.

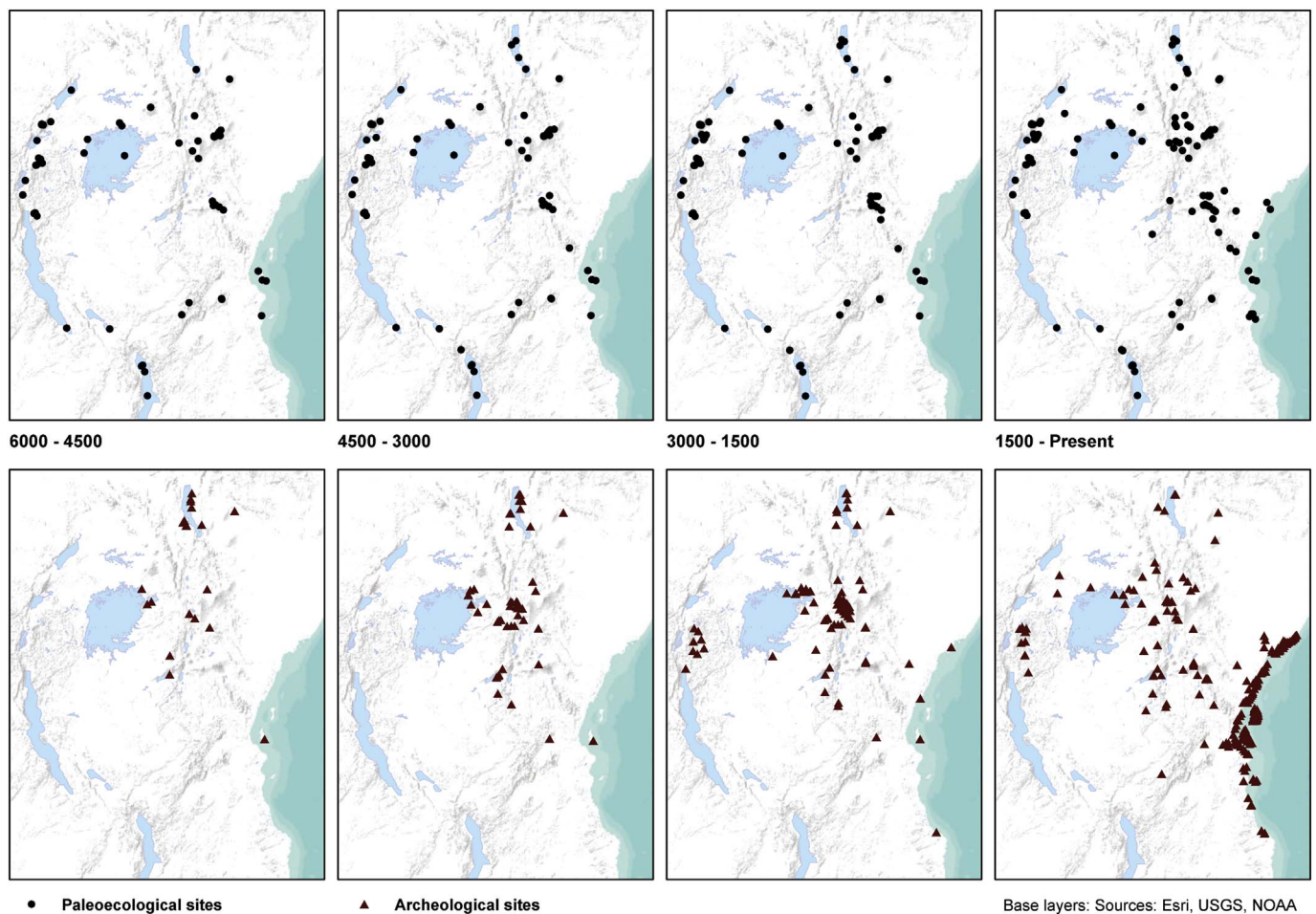


Fig. 16. Comparison of Palaeoecological and Archaeological sites distribution by time bands of 1500 years from 6000 years BP to present time.

As mentioned above, the spatial disconnect between palaeoecological and archaeological sites mitigates against direct comparison between the evidence for environmental and cultural history and, as such, the ensuing descriptions entail a degree of uncertainty. In keeping with the presentation of the palaeoenvironmental data and the evidence on human history, the interconnections between the two sources of information will also be presented within the same time periods.

4.1i. Environmental-human interconnections from 6000 to 4500 yr BP (Fig. 16A and E)

After the early Holocene warming and associated rise in lake levels (Stager et al., 1997; Stager and Johnson, 2000; Verschuren et al., 2009), the period from 6000 to 4500 yr BP marked a change to more arid conditions (see Section 3.2). This change has been seen through a transition in vegetation from forests to open grassland, and where a significant lowering of the lake levels occurred. The archaeological record for the early part of this period is generally scarce with the majority of finds consisting of evidence of harpoon bone and fish bones around the lakes in the region (Phillipson, 1986, 1988, 2005). Garcin et al. (2012) note that the main mid-Holocene cultural transition appears to be closely related to the timing of the documented c. 50 m fall in lake water-level in the Turkana Basin from around 5300 yr BP. They suggest that the shrinking of the lake exposed large areas (c. 10,000 km²) of silts conducive to the grazing of animals, which in turn, coincides with the beginnings of pastoralism in the area. However the radiocarbon dates from the earliest archaeological evidence for pastoralism at the sites around Lake Turkana, e.g., Dongodien (GaJj2),

Koobi Fora Ridge (GaJj2) (Owen et al., 1982) and FwJj5 (Ashley et al., 2011) suggest that there was an initial lag following this pronounced environmental change and then a gradual take-up of pastoralism in relation to this newly available land. This potential of a temporal lag is further supported by Tierney et al.'s (2013) observation for the Tanganyika Basin whereby the terrestrial ecosystem has an inertia or resilience in responding to climatic stress, and vegetation change appears to have contributed to abrupt hydrologic change; although there are uncertainties due to dating precision and intercomparison. Whilst a general trend towards a drier environment occurred in East Africa from this period onwards, vegetation change was often nonlinear, highly variable spatially and appears to have been dependent on specific ecosystem resilience to aridity at the local and regional scale (Willis et al., 2013).

The environmental and archaeological evidence for this period would suggest that people were reacting to the changing availability of resources as the climate changed, albeit slowly and after an initial lag. For the period 6000–4500 yr BP, archaeological research has focused around lakes (Figs. 12 and 16) (Barthelme, 1985; Karega-Munene, 1993; Beyin et al., 2017). How people responded to the increasing aridity in areas away from large bodies of water is largely unknown, and whether this spatial clustering is real or a result of targeted fieldwork is an area for future investigation.

4.1ii. Environmental-human interconnections from 4500 to 3000 yr BP (Fig. 16B and F)

Around 4000 yr BP clear indications for an abrupt arid event are evident in the ice core record from Kilimanjaro (Thompson et al., 2002), which can be correlated to similar events across tropical Africa

(Marchant and Hooghiemstra, 2004) between 4100 and 4300 yr BP. A major drying event around 4200 yr BP has been widely detected and dated, and linked to a series of droughts that were responsible for events such as mass extinctions on Mauritius (de Boer et al., 2015).

Archaeologically, during this period we see an expansion of pastoralist activity (Coughenour and Ellis, 1993). However, there is a significant caveat to assessing the impact that severe drought events may have as the palaeoenvironmental and archaeological records may not be well enough resolved (in terms of chronology and sampling) to detect these short-term, but intense, events. Where it has been possible to examine the impact of this, it has been within a closed island system and with animals who are not able to escape those conditions (e.g., de Boer et al., 2015), whereas people will arguably move to new areas. Whilst we may be seeing this with the expansion of pastoralism in East Africa at this time, as pastoral populations expanded farther southwards from an increasingly dry Sahara, finding the direct chronological and environmental link between people and the climatic events is still elusive.

4.1iii. Environmental-human interconnections from 3000 to 1500 yr BP (Fig. 16C and G)

Evidence suggests that the general drying of the climate seen in the preceding periods continued during 3000–1500 yr BP. Simultaneously during this time there is a cultural shift, where we start to see evidence of iron working within the region, initially to the west of Lake Victoria (e.g., van Gruntherbeek et al., 1982, 2001; Schmidt, 1997a). This technological shift is of particular importance when discussing the relationship between people and their environment, because it is arguably the first time that people affected the environment around them as much as climate had done in preceding periods. This human impact on the vegetation is often assumed to have been caused by the need for fuel in the iron production process (Bayon et al., 2012; Bostoen et al., 2015) and the forest clearance for building and agricultural expansion to support a [rapidly] growing population (Taylor, 1990). Evidence for these causal effects is extremely limited, however, and the direct impact from iron smelting was probably minimal, the real link to deforestation being that iron arrives with farming and enables vegetation clearance for agriculture. Charcoal assemblages from excavated iron working sites in Buhaya, to the west of Lake Victoria show a change from exploiting wet forests that were known to have grown on the edges of the water around 1950–1750 yr BP, to taxa associated with secondary regrowth and swamp areas by 1550 yr BP; a change also loosely corroborated in the pollen record (Schmidt, 1997b). Another example can be seen from the Pare Mountains in northern Tanzania, where increased erosion is recorded in the sedimentary records from 2000 yr BP, which correlates well with the arrival of agriculture and ironworking in the area (Heckmann, 2011; Heckmann et al., 2014). Pare was a centre of iron production from at least from at least c. 1100 yr BP and several iron smelting and smithing furnaces in North Pare have been excavated. Archaeometallurgical research on samples recovered from these sites suggest that the industry was relatively fuel efficient, despite some variations in raw materials selection and smelting technologies over time. More critically, it is clear from the geoarchaeological studies that soil erosion had been initiated prior to the intensification of smelting activity which nevertheless continued well into the modern era.

In the examples above, the benefits of multi-proxy studies are made clear, especially when these include evidence of both cultural activities and environmental change and more so when there is direct evidence of environmental exploitation by people through the charcoal and geoarchaeological record. More often than not, we are left with only one of those types of evidence and forced to make inferences to nearby studies that can be of a very different context and at a vastly differing resolution. This has led to heated debates about causes of environmental change (e.g., Maley et al., 2012; Bayon et al., 2012). How we bring datasets together to determine the ecological consequences of human activities in different environmental settings - whether these

datasets are in close proximity to each other or over larger areas - is a complex issue (Marchant and Lane, 2014).

4.1iv. Environmental-human interconnections 1500 yr BP to the present (Fig. 16D and H)

The evidence from both the archaeological and palaeoecological records (with the addition of historical evidence for the later part of this time period) is better resolved than for any other period under review here. This increased body of evidence suggests that the environment of the past 1500 years is characterised by a highly variably hydroclimatic regime (Nash et al., 2016). In the western sectors of the East African plateau, the driest conditions of the entire Holocene seem to have been already registered around 2000 years ago, followed by a modest long term wetting trend (Nash et al., 2016). Lake levels fluctuated by tens of meters over decadal timescales. In addition to inundating or exposing low-lying areas around the numerous East African lakes, this hydrological change also resulted in contraction and expansion of swamp forest (Rucina et al., 2010). In addition to mean change in hydrology, it is most likely that this period of climate variability was characterised by shifts in seasonality of rainfall that would have, as today, impacted on farming communities. Pastoral populations would have been able to buffer their livelihoods against this climate variability and change by migrating to new pasture (Waller, 1985); such a system of transhumance would have been severely challenged under periods of rapid onset of aridity. One such period associated with large-scale movement of cattle and culture is associated with the arrival of the ancestor's of the Maasai into East Africa from more northerly locations. It is thought the Maasai's ancestors and their cattle migrated into East Africa around 500 years ago (Galaty, 1993). The ability of pastoralists to migrate in response to environmental challenges has been increasingly curtailed, especially by processes of land enclosure, protected area expansion and rangeland fragmentation, culminating in the situation today of limited grazing options and enhanced vulnerability (Pfeifer et al., 2012). Secondary farming communities would also have to cope with this period of climate variability and shifts in seasonality of rainfall. This coping ability would have been helped by an ever expanding number of crop types initially based on African domesticated tubers and cereals, supplemented by a wide range of leafy greens and arboreal species, with increasing exploitation of non-African domesticates introduced from across the Indian Ocean and, post-Columbus, the Americas (Fuller and Hildebrand, 2013). These last two locations have provided the source for two of the most common staple food crops across the region - maize and plantain bananas (McCann, 2007). This contact with the Americas, alongside increasingly influential global trade, fuelled the exploitation of the region; initially this focused on slaves and ivory between the fifteenth and nineteenth centuries CE (Alpers, 1975; Austen, 1988; Beachey, 1967; Sheriff, 1987). As well as resulting in a significant reduction in the size of East African elephant populations from the millions to the tens of thousands (Milner-Gulland and Mace, 1991), which in turn would have had a number of ecological consequences (Håkansson, 2004, 2007; Lane, 2010), the caravan routes associated with the trade provided conduits for the passage of new crops, technologies, the movement of people and wealth, the restructuring of labour, and the transition to a service food-producing economy (Koponen, 1988). This transition may have resulted in extensive agricultural expansion focused along the main trade routes from the coast through to the interior of the East Africa, as has been argued by Håkansson (2004). It should be emphasised that the recent period has not just been characterised by increasing human impact. For example, an extensive Rinderpest outbreak around 120 yr BP is known to have decimated pastoral herds and the lives of their pastoral communities, resulting in a relatively depopulated and green landscape that gave early colonial governments an atypical impression of the landscapes of East Africa (Kjekshus, 1996).

Over the past century, East Africa has experienced substantial demographic growth, both indigenous, and as a result of large influx of

immigrant populations. Increasingly mobile flows of people, goods and services, combined with population growth and associated land-use changes have led to a general degradation of the landscape including deforestation and soil erosion (e.g., [Snelder and Bryan, 1995](#); [Johansson and Svensson, 2002](#)). Intensive agriculture was introduced, for example, to Lobo and Amboseli about 50 years ago, and cultivation has increased as more of the population has switched to subsistence or industrial farming ([MEMR, 2012](#)). This seems to be a common trend throughout East Africa as traditional transhumance practices, increasing climate variability, and access into markets have made sedentary farming a more profitable livelihood.

4.2. Temporal and spatial gaps in the data and ensuing impact on extrapolation

Temporal and geographic gaps in sampling effort need to be addressed, and in some cases, new research on geoarchives adjacent to archaeological sites will be necessary to assess their palaeoenvironmental potential in areas with no lacustrine or palustrine deposits. The scientific community should aim to identify innovative trans-disciplinary projects that integrate archaeology, palaeoethnobotany, archaeozoology, physical geography and ecology ([Eggert, 2005](#)). The palaeoecological record shows that there is a fairly even spread of sites across all four periods albeit with an increased number of sites towards the most recent period ([Figs. 9 and 16A–D](#)). In contrast, the number of archaeological records increases dramatically towards the present day, particularly along the coast ([Figs. 12 and 16E–H](#)). Interestingly, for both the archaeological and the palaeoecological sites, the distribution is concentrated in certain locations - for the latter this mainly reflects the distribution of sedimentary basins. For archaeological sites there is a concentration along the coast, along the present-day road network and around key locations ([Fig. 15](#)) whereas large areas, such as southern Tanzania and northeastern Kenya, remain relatively under explored. The archaeological evidence does however show a change in the location of sites through time - notably on the coast there is an expansion as the Swahili trade developed with the Middle East and trans-Indian Ocean locations ([Wynne-Jones, 2016](#)). Whilst this may represent the choices of people in the past, we should keep in mind it is potentially reflecting the choices of people in the present as well. These choices may reflect themes that are currently of interest to the research team and also choices of publication method. There are considerable numbers of artefacts produced by the practicalities of conducting fieldwork, with many reported sites being close to present day road networks ([Fig. 15](#)). Particularly interesting sites may have had multiple studies conducted on them; for example Engaruka was first visited by L.S.B. Leakey on his way to Olduvai in 1935 and then worked on by a succession of scholars (e.g. [Leakey, 1936](#); [Sassoon, 1967](#); [Sutton, 1978](#); [Robertshaw, 1986](#); [Sutton, 2004](#); [Stump, 2006](#); [Westerberg et al., 2010](#)). There is also a difference in the visibility of the research: almost all of the palaeoecological and climatic research that has been undertaken in East Africa is dated and published in widely circulated scientific journals. The same cannot be said of contemporary or historical archaeological research, where a lot of undated and inaccessible or unpublished work has been undertaken more locally and also by amateurs and antiquarians in the past. Therefore, there is a strong need for the creation of a digital database of archaeological sites and monuments for the region as a whole.

4.3. Harmonising datasets and interlinking databases

Data are presented in a multitude of ways and are stored in different real and virtual locations with independent structuring. Although this can improve visibility and local accessibility, it highlights the need for common standards and appreciation of the potential use and application for other disciplines and by non-specialists. The body of archaeological and palaeoenvironmental data is rapidly growing, with new

techniques allowing previous interpretations and contexts to be revisited. This growth highlights the need and requirements for data archiving, accessibility, and on-demand visualisation of complex datasets for multiple end-user audiences. The use of these data should not be exclusive to the realm of scientific enquiry, but should be made available to a broader audience in the private and public sectors, non-governmental organisations, and private citizens for research, context, policy and management guidance, entertainment, education and training ([Courtney-Mustaphi et al., 2014](#); [Keeso, 2014](#)). Certain types of metadata and data that have yet to be thoroughly archived are at risk of disappearing or having reduced efficacy or scientific usefulness. The highly dispersed nature of these datasets covering East Africa means that previous syntheses ([Mgomezulu, 1981](#); [Ambrose, 1984](#); [Courtney-Mustaphi and Marchant, 2016](#)) and palaeoenvironmental databases ([Marlon et al., 2016](#); [Sánchez Goñi et al., 2017](#)) remain incomplete and some are relatively static with few updates - a situation this current compilation from East Africa will aim to resolve for the region, and feed into the Global LandCover6k project ([Gaillard and LandCover6k, 2015](#)).

5. Application of perspectives on 6000 years of land use change across East Africa

One of the key rationales for conducting this review is to explore the linkages between our current understanding of land-cover change and human interaction for the past 6000 years, and to examine the potential wider applications of such past insight into contemporary issues. Such potential application falls within a wide and increasing number of areas but we will focus on four diverse examples: developing methodologies for further understanding human/environment interactions, ecosystem and climate modelling, ecosystem services and biogeochemical cycling, and finally conservation and sustainable development. The range of topics have been chosen so as to highlight the potential breadth for the utility of these combined datasets, and the insights they can produce for a range of disciplines.

5.1. Developing methodologies and understanding of human environmental interactions

Clearly, understanding human interaction with environmental change can be of relevance to society, politics and the economy, but to fully utilise these insights and incorporate them into future trajectories, we need to understand and integrate long-term perspectives ([Crumley, 1994](#); [Gillson and Marchant, 2014](#)). We have shown above how sedimentary sequences can contribute to our wider understanding of environmental history in East Africa, especially for periods when the instrumental records are relatively short and incomplete. At times however the records appear to contradict one another, or cannot provide the data resolution required to answer the question at hand. Further research is needed to better understand the processes that have led to sediment formation (e.g. taphonomic processes), to optimally address issues of sampling resolution and chronological control) and how we integrate these records with data, and into models, created by other disciplines.

Whilst the geographic gaps in the datasets ([Fig. 15](#)) need to be addressed, additional challenges are also present when dealing with archaeological and palaeoenvironmental data. The main issue is the differing chronological scales, these vary from the seasonal to annual response of farming communities to the decadal to centennial scale resolution of palaeoenvironmental studies. This is often reflected in the different implicit meanings of commonplace phrases, such as 'long-term', 'sustainable' and 'resilient', which may be understood by scholars from different disciplines in quite different ways ([Stump, 2010](#); [Bollig, 2014](#); [Lane, 2015b](#)).

There are also practical challenges that need to be addressed, as well as methodological and conceptual issues. For instance, currently most pollen records have a temporal resolution > 50 years, these do not

permit a thorough investigation of the timing and impact of changes due to human populations. However, by employing high resolution analysis in conjunction with robust chronology construction it should be possible to make interpretations at the scale of a single human generation (Bayliss, 2009), and to link records and engage with issues that are specifically relevant to historians, geographers and anthropologists (Haberle and Chepstow-Lusty, 2000). This is only achieved by the careful initial selection of samples, gaining a sufficiently large number of radiocarbon determinations, utilising fine-scale radiometric techniques (e.g., ^{210}Pb and ^{137}Cs) on the upper sections of cores (e.g., Ssemmanda et al., 2005; Gillson, 2006; Finch et al., 2017) and employing predictive (as well as retrospective) Bayesian age-depth modelling techniques to provide more robust and precise chronologies (e.g., Öberg et al., 2013).

To fully understand the interactions between environments and people, a perspective that combines *in situ* site-specific studies and explores the spatial relationships with existing archaeological and palaeoecological insights is fundamental (Ekblom, 2012; Ekblom et al., 2017). The *mélange* of information preserved in sediment cores can be complicated due to climate change and human activity operating in tandem; identifying cause and effect is highly challenging with current approaches. There is thus a pressing need in studies of late-Holocene sediment cores for the careful selection of sites and for a full consideration of all factors that are likely to have affected the proxies and also forced change in the conditions within the catchment areas of sedimentary basins. Many new methods are available for use on sediment

cores, but they currently remain the exception in East Africa, rather than the norm. These include, the analysis of plant macrofossils (Birks and Birks, 2000), grass cuticles, phytoliths (Alexandre et al., 1997), non-pollen palynomorphs (Ekblom and Gillson, 2010; Ejarque et al., 2011), and a suite of developing geo- and bio-chemical techniques through chemical archaeology (Crowther et al., 2017).

As reviewed here, there is an increasing amount of palaeoenvironmental and archaeological information from East Africa (Fig. 15). As the datasets continue to increase in both quality and quantity, it also becomes necessary to develop new theoretical models that are conceptualised to accommodate both types of information that are acceptable to all disciplinary perspectives (Bird et al., 2005), as well as the wider ontologies of the disciplines that produce the data, as they sit within both the sciences and the humanities (Mazzocchi, 2006). We will never know exactly how people in the past perceived their environments, or the changes that occurred within them, but documenting the evidence of these complex interactions between people and the environment, understanding the mechanisms by which the signals of activity are recorded in the sedimentary records and working to theoretically combine different types of evidence (Richer and Gearey, 2017a, 2017b) are some of the first steps to be undertaken before we can fully start to inform current and future responses to conservation and land-use strategies (Figs. 17 and 18).

Towards this goal, categorization schemes have been developed in order to map and quantify land use across space and time, whether on global (e.g. Morrison et al., 2016; Phelps and Kaplan, 2017; Widgren, in

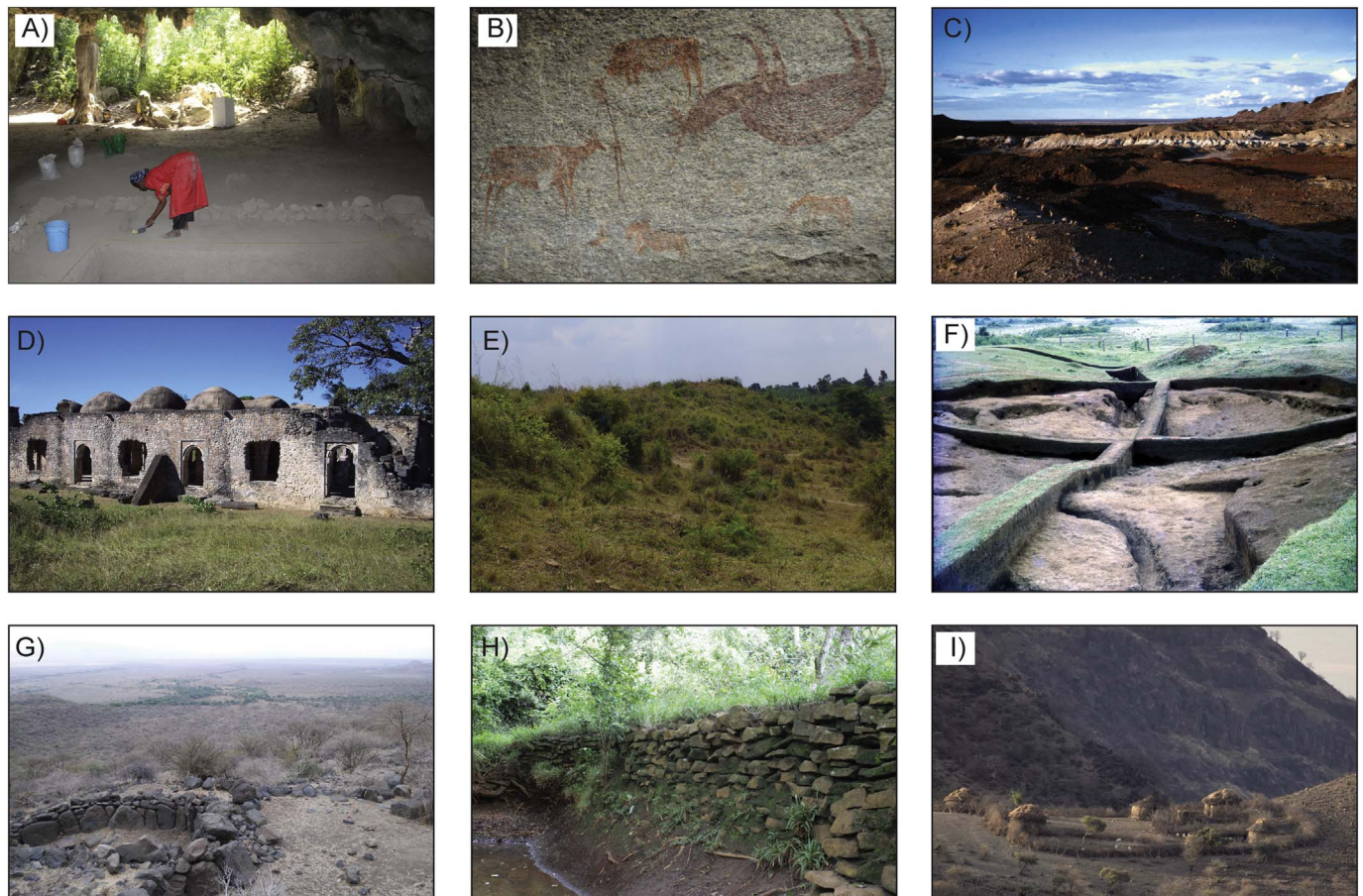


Fig. 17. Examples of archaeological sites. A) Kuumbi cave on Zanzibar (photo: Ceri Shipton). B) Rock art from Kondoa rock art World Heritage Site, Central Tanzania. Rock art associated with Holocene hunter-gatherers rituals of the Sandawe and the Hadzabe that date to 5000 to 20,000 years ago (photo: Emmanuel Bwasiri). C) Early Holocene shell beds at the site of Lothagam in northern Kenya (photo: Larry Robbins). D) The Great Mosque of Kilwa Kisiwani, along the Swahili coast of Tanzania (photo: Stephanie Wynne-Jones). E) The 'bwogero' earthworks at Ntuusi, Uganda (photo: Andrew Reid). F) Sirikwa holes, Kenya, dating from 850 to 550 yr BP (photo: John Sutton). G) The abandoned irrigated agricultural site of Engaruka, Tanzania, occupied from c. 600–150 BP with former habitation platforms in foreground and former field system in the plain beyond (photo: Daryl Stump). H) Traditional irrigation reservoir (ndiva), North Pare Mountains, Tanzania (photo: Daryl Stump). I) Contemporary boma (pastoral enclosure) site in northern Tanzania (photo: Suzi Richer).

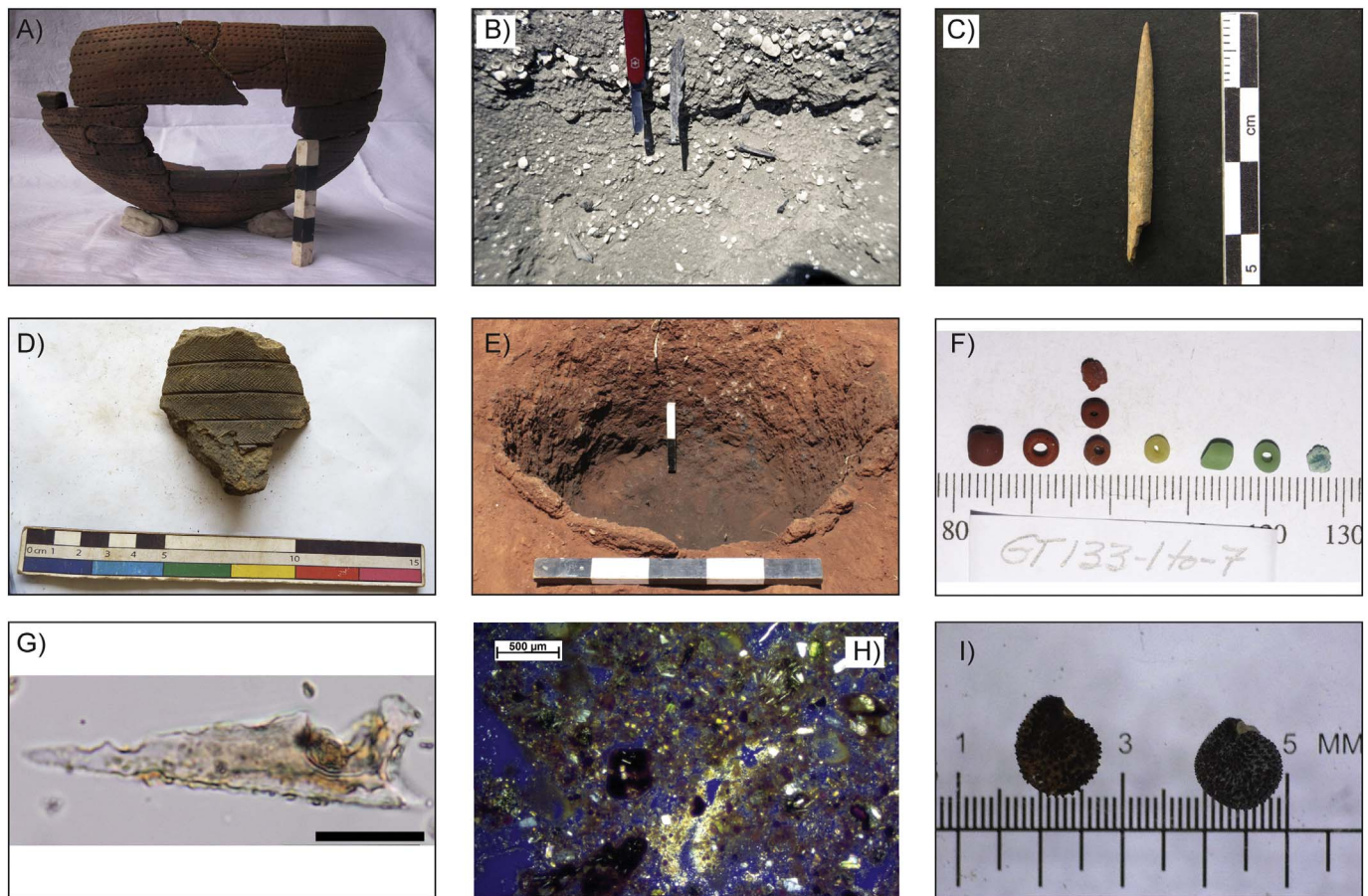


Fig. 18. Examples of archaeological evidence. A) Kanyore Ware, reconstruction by Ceri Ashley (photo: Ceri Ashley). B) Barbed bone point (harpoon) in situ in early-mid Holocene shell beds at Lothagam, Kenya (photo: Larry Robbins). C) A worked bone implement from the site of Luxmanda, Tanzania. Made on the limb bone of a caprine-sized mammal. Interpreted by Langley et al. (2017) as a projectile point tip (photo: Mary Prendergast). D) Urewe Ware from Lolui Island, Uganda (photo: Oliver Boles). E) Excavated iron smelting furnace, Mwanga, Tanzania, this example dated to 650 to 510 cal BP, scales in 10 cm increments (photo: Stump, 2010). F) Wound glass beads from 14–15th centuries CE, from excavations at Songo Mnara (photo: Steph Wynne-Jones). G) Hair Cell Phytolith from Songo Mnara, Tanzania in association with a wattle and daub structure, scale is 20 µm (photo: Hayley McParland). H) Micrograph of soils from within an historically irrigated field at Engaruka, Tanzania (photo: Carol Lang). I) Non-charred (left) and charred (right) *Portulaca oleraceae* seeds. This species is a beneficial agricultural weed in East Africa with shallow roots that help retain soil moisture in dry environments (photo: Senna Thornton-Barnett).

press) or regional scales (Kay and Kaplan, 2015; Widgren, in press). As part of the project *Mapping Global Agricultural History*, which aims to map agricultural development at the global scale during the last millennium Widgren (2010) presents (Fig. 19) a slightly revised excerpt based on a continental map covering sub-Saharan Africa (Widgren, in press). Here, the focus is not on land cover *per se*, but on the delimitation of the dominant global agricultural systems in the sense of Whittlesey (1936) and Grigg (1974). Land use/land cover within each polygon can thus be varied, but at a general level there is covariation between type of agricultural system and land use/land cover. Within this project seven such broad categories of agricultural systems have been identified globally (1–7) (Widgren, in press). The category “Extensive or undifferentiated agriculture” (3 on Fig. 19) refers on the one hand to areas where agriculture is known to have been extensive (e.g. slash-and-burn), but also to areas where agriculture is known to have existed, but its character is not yet documented. Further subdivisions of these seven categories have been made for Africa (Widgren, in press).

Similarly, the ACACIA project (Kay and Kaplan, 2015) is working at the sub-Saharan scale and is synthesizing archaeological data from published studies to categorize and map land use at key time periods during the middle and late Holocene in sub-Saharan Africa. These categories and maps will then be used to drive the human element in coupled human–environment models that are presently additive and do not represent the pulsed, and sometime rapid, nature of change (Fig. 20). The first attempt to categorize land-use patterns in prehistoric

sub-Saharan Africa relied on existing socio-cultural categorizations and showed how the footprint of a society can be quantified at various scales based on their diet, technology, and economy (Kay and Kaplan, 2015). Subsequent work has focused on the specific effects and terminology used to describe pastoral societies (Phelps and Kaplan, 2017), and mapping agricultural livelihoods in West and western Central Africa (Kay et al., 2016), although the methodology used and many of the categories could easily be applied in East Africa. An emphasis in this work has been to acknowledge the multi-scalar nature of the data and how this impacts on the ensuing reconstruction. For example, the presence of a particular domestic crop in a region does not mean that the only land use was farming. Many of the livelihood categories incorporate farming to varying degrees, and the evidence indicates that there was a mosaic of livelihoods, and therefore land uses, present in the landscape at any one time. By approaching the human–environment interaction in this way, it is hoped that a better understanding will be gained about how humans have not just responded to, but also influenced the environments of sub-Saharan Africa over the last several thousand years.

5.2. Linking palaeoinformatics with Climate and ecosystem models

In addition to improving our ability to reconstruct and understand the processes of past environmental change, and to explain mechanisms that might be responsible for such variability, there are many potential

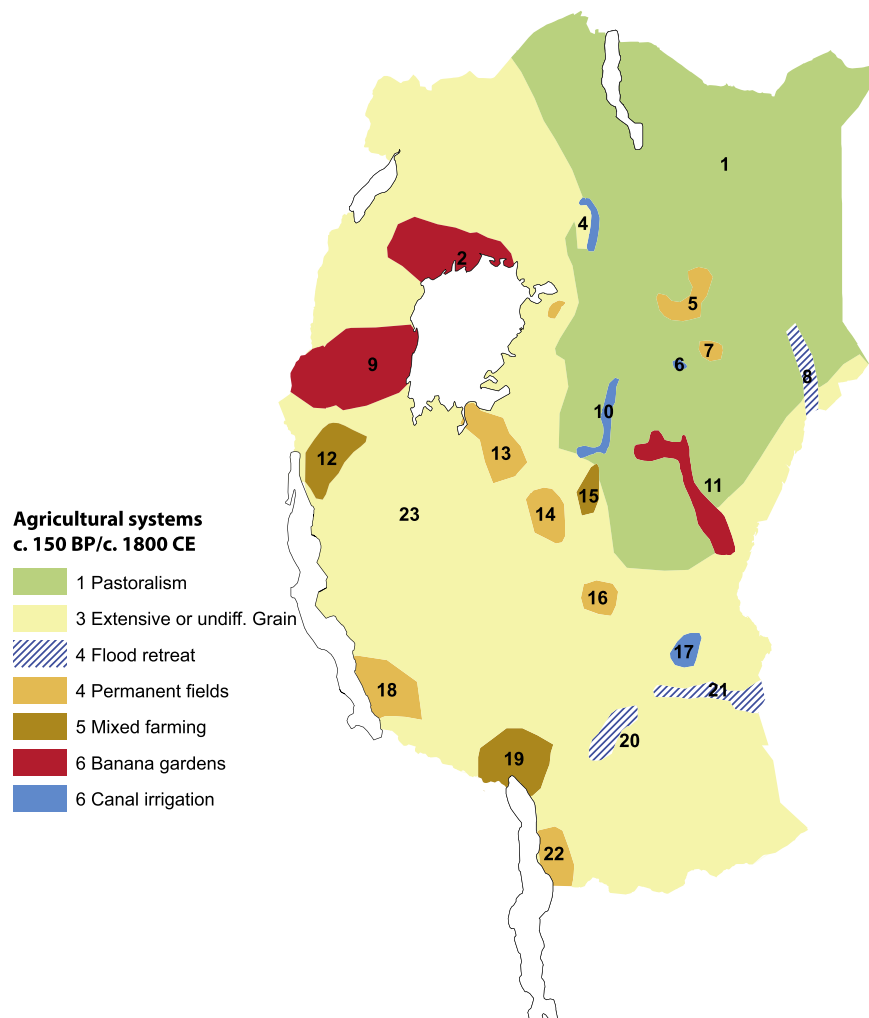


Fig. 19. Agricultural systems from 150 BP (c.1800 CE) in East Africa. Image is based on, and revised from an original publication by Widgren (in press). Figures in the map refer to place names and references listed in SM5.

benefits of combining data-based with model-based interpretations of change (Jolly et al., 1998a). An understanding of past environmental history is crucial for both providing context into regional climate change assessments through to validating global and regional climate model simulations when these are hindcast (Braconnot et al., 2012). Africa is cited by the Intergovernmental Panel on Climate Change as a continent where proxy-based climate reconstructions are currently too limited to support regional climate change assessments (Masson-Delmote et al., 2013); with the increasing desire for long-term regional climate models, this makes the need for proxy evidence of environmental change even more pressing. Climate models are the tools used to understand the future climate of the Earth. There are some 18 General Climate Models (GCMs) used throughout the world that have been developed by different governmental institutions (IPCC, 2013). Although these different climate models are based on physical laws of thermodynamics, how they are implemented and how they consider land surface feedbacks and ocean–atmosphere–land interactions varies considerably between models and requires coordinated inter-comparison projects. As a consequence, regionally-specific temperature and precipitation reconstructions can vary tremendously across the various models and predictions, which tend to rely on multiple ensemble GCM outputs under different scenarios of greenhouse gas concentration (Hitz and Smith, 2004; Monerie et al., 2012). Added to this are the numerous discrepancies between modelled and data-based views of past climate variability in East Africa (Rowell et al., 2015). For

example, changes in the African monsoon strength have long been a subject of considerable research interest (e.g. Harrison et al., 2001, 2003), with particular attention being given to the most recent period of maximum extension and intensity of the northern monsoon domain, the so-called African Humid Period, which took place 14,800–5500 yr BP (*sensu* deMenocal et al., 2000), and which caused a ‘greening’ of the Sahara (Claussen and Gayler, 1997; Hoelzmann, 1992; Hoelzmann et al., 1998). Many modelling studies conducted in northern Africa currently underestimate the apparent amplitude of change during this period (Braconnot et al., 2012; Harrison et al., 2015; Perez-Sanz et al., 2014). Similarly, there is uncertainty about the rapidity of the expansion of the Sahara from the mid-Holocene and the role that people may have played in this (Hoelzmann et al., 2001; Wright et al., 2017).

Progress towards improved modelling skills, and a better understanding of the mechanisms that drive abrupt changes in climate, should be expected from both the climate modelling and palaeoenvironmental communities as increasing use is made of palaeoclimatic data sets to provide context for anthropogenic warming (Braconnot et al., 2012; Clark et al., 2002). One of the current problems encountered in the application of modelled outputs has been a discrepancy between the observed and the predicted, this is because vegetation and climate often change in a nonlinear fashion, instead being affected by cycles, pulses, and reversals caused by factors such as soil moisture, vegetation change and albedo feedbacks (Friedlingstein et al., 2006; Ganopolski et al., 1998). One of the other key areas for future GCM development is to

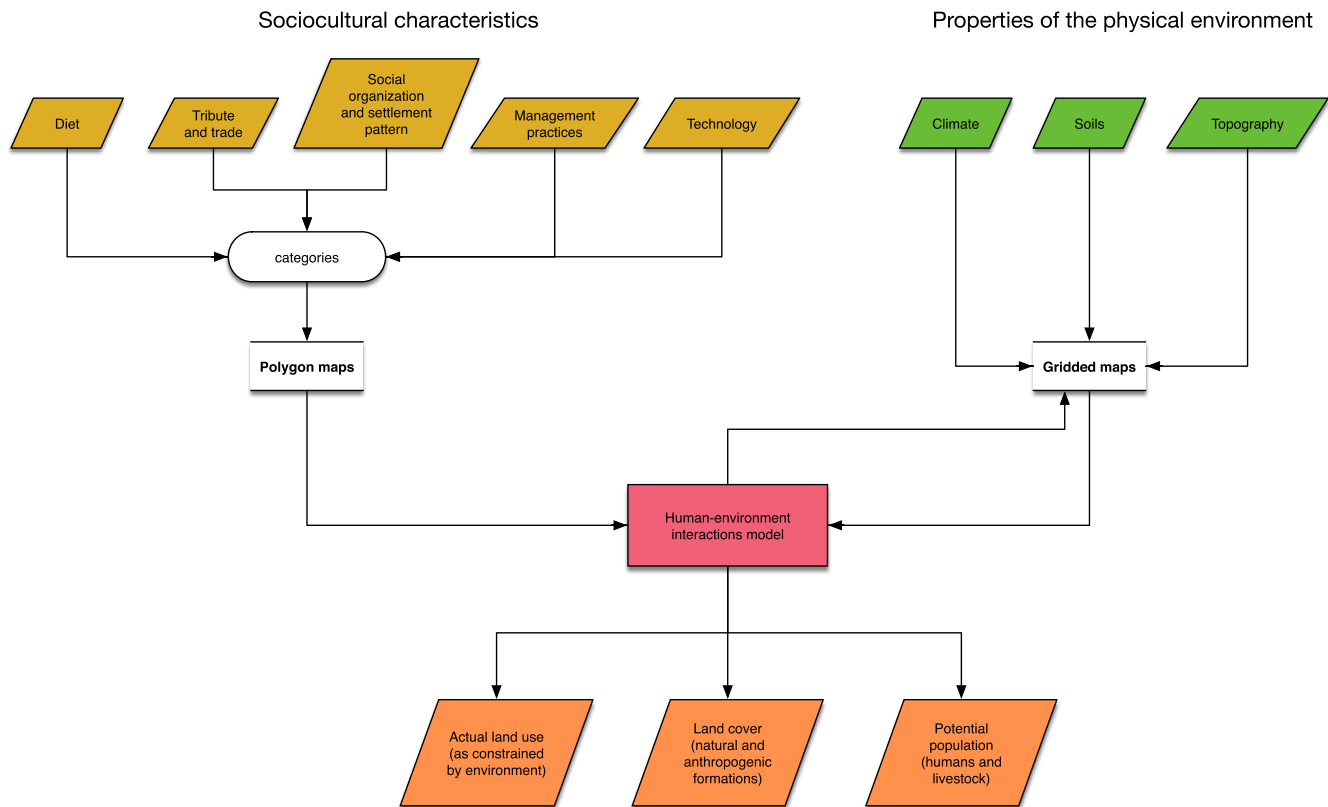


Fig. 20. New strategy for modeling human–environment interactions in the past. This schematic shows how human–environment interactions are influenced both by factors that may be predicted on the basis of the properties of the physical environment, and by many socio-cultural characteristics of the people who lived at any given place and time. While observations and reconstructions of climate, soils, and topography inform the former category of data, the latter may be driven by archaeological, historical, and ethnographic observations, as changes in the socio-cultural system are difficult to predict. Both types of data are brought together in the human–environment interactions scheme, which at its core is a vegetation and crop-productivity model. The model results include predictions of land cover and land use, population, and additional properties of the physical environment, such as carbon storage and water cycling.

incorporate vegetation changes and how such changes may feedback to the climate system (Foley et al., 1998; Doherty et al., 2000; Richardson et al., 2013; Chevalier et al., 2017). Within Africa, rapid switching between wet and dry phases has also been linked to positive feedbacks in the changes in vegetation, soil and albedo (Claussen, 1997; Claussen et al., 1999; Knorr et al., 2001; Friedlingstein et al., 2006). Additionally, increasing in land surface albedo, caused by anthropogenic vegetation change, can produce similar feedback processes that ultimately result in climate change (cf. Kutzbach et al., 1996; Doherty et al., 2000). An East African example of the albedo effect can be seen in the conversion of savannah grassland mosaic to a semi-desert environment. This has resulted in significant changes to surface dynamic parameters such as albedo, surface roughness, leaf area index, and fractional vegetation coverage. Collectively, these have altered water and energy exchange between the ground surface and the atmosphere, which in turn has affected the timing and intensity of the monsoons (Lamb et al., 1989; Claussen, 1997; Claussen et al., 1999; deMenocal et al., 2000).

Given this importance of land cover for influencing Holocene weather and climate patterns in East Africa, and the growing recognition that human activities are at least as important as climate in causing land-cover change, especially over the last 3000–4000 years, there is a growing realisation that more comprehensive and thematically resolved information on human systems is required to drive the next generation of Earth System models (Fig. 20). More and better data about how people have influenced African landscapes in the past will ultimately lead to an enhanced predictive capability and an improved match between model-based and data-based reconstructions of past climate and environments. At present, those Earth System Models (ESMs) that take

anthropogenic land-cover change into account generally rely on simple model-based scenarios of a poorly defined single variable called “land use” from e.g., the HYDE (Klein Goldewijk et al., 2011; 2017) or KK10 scenarios (Kaplan and Krumhardt, 2011; Kaplan et al., 2011). These scenarios are generally additive views of land cover and population change that tend to do a poor job of reflecting the nature and magnitude of land-use and anthropogenic land-cover change, particularly in Africa. Indeed, a key rationale for the wider PAGES LandCover6k initiative - into which the data behind this review will contribute - is to provide data-based global surfaces of land cover at 6000 yr BP, 500 yr BP (1500 CE) and 150 yr BP (1850 CE) relating respectively to the mid-Holocene ‘optimum’, latest pre-colonial period, and the latest pre-industrial times. These global surfaces of land cover will then provide a data-based test of GCMs (Gaillard et al., 2015; Morrison, in press).

As changes in land use and land cover can significantly affect how the planet functions and in particular that they can cause changes in local and regional climates (Claussen and Esch, 1994; Chase et al., 1999) they both have implications for understanding how the ecosystem in the past, present and future has supported and can support human needs (Vitousek et al., 1997). An important aspect of the recent Framework Convention on Climate Change, hosted by the United Nations in Paris towards the end of 2016, was the development of plans to integrate climate change perspectives into new policies and programs that aim to enhance adaptive capacity, strengthen resilience and reduce vulnerability to climate change. The currently anticipated changes to the planet's climate poses threats to biodiversity and natural resources, human health, food and water security, public health, natural resources and biodiversity (Swallow et al., 2009). Clearly models that investigate the impact of future change on our ecosystems, crop systems (Thornton

et al., 2007), and the ensuing potential of nature-based solutions for development, have to be testable. As with the GCMs, the only temporal data to provide such a test of model performance are those data sets generated from the past such as presented here.

In addition to impacts from climate systems, changes in atmospheric composition are changing ecosystem-environment relationships. Under the present situation of increased CO₂ concentrations, there is increasingly ‘closed’ savannah, not primarily as a result of CO₂ fertilisation, but as a result of increased water-use efficiency and the ensuing growth rates (Midgley and Bond, 2015). In water-limited environments, such as savannahs, increases in atmospheric CO₂ concentrations can promote increases in plant water-use-efficiency, net primary productivity, and enhanced carbon storage (Midgley and Bond, 2015). Current GCM projections for East Africa suggest a climate that will be warmer and wetter, with enhanced net primary productivity, associated carbon storage, and increased runoff. All of which are likely to contribute to increases in both tropical broadleaved evergreen forests and tropical broadleaved rain-green forests (Doherty et al., 2010). Such a broad-scale prediction across a region of clear environmental and ecosystem complexity (Section 2.2) is clearly open to error, and many more regionally focused modelling approaches are needed to capture the range in spatial variability (Platts et al., 2015). It is clear from the palaeoenvironmental data reviewed above (Section 3) that spatial variability and complexity existed in the past, with some areas getting drier and others getting wetter, and this is likely to continue in the future (Fig. 21).

A variety of models are available to investigate individual species or ecosystem responses to climate change (Platts et al., 2013, 2015) and land-use change (Jung et al., 2016). To date, one of the most popular methods for investigating the responses that plants have had to climate change has been species niche modelling, or bioclimatic modelling (Araújo and Peterson, 2012). Climatic envelopes are created by correlating the known distribution of the species in question with various ecological and climatic parameters – the effect is to create a niche which represents the boundaries within which that species can survive. As the ecological and climatic conditions are both known for the present, to some extent the past, and can be predicted for the future, it allows hypotheses to be generated concerning how the species distribution may change in relation to climate change (e.g., Maiorano et al., 2013). Combining palaeoecological and metacommunity approaches has the potential to be a very fruitful combination to engage in a truly comprehensive analysis of the processes regulating ecological communities (Svenning and Sandel, 2013). For example, such a combination will allow us to understand transition mechanisms in savannah ecosystems: such as how they change from woodland to apparently stable grassland ‘phases’, how they can be resilient to disturbance and how they can persist over the long-term and still withstand disturbance (Li, 2002). Fire and/or herbivory, primarily by elephants, are usually the causes of disturbance that are responsible for the transition woodland to grassland savannah. However, transitions from grassland to woodland occur less frequently and more slowly (Bond and Midgley, 2000), relying primarily on recruitment events, and are likely to be hampered by browsing. In situations where factors such as disease or hunting affect herbivore numbers, the transition from grassland to woodland occurs more quickly (Dublin, 1995).

In addition to providing a data-based test for models, and providing an input of changed land surface to climate models, the long term perspective of land-cover change presented here can be used to provide context for more contemporary analysis of land-cover change. For example, over the past 50 or so years the timing, direction and rate of land-cover change can be assessed by looking at remotely sensed images (Pfeifer et al., 2012). This study analysed land-cover change across East Africa from two paired MODIS land-cover images taken in 2001 and 2012, which clearly show the continued expansion of agriculture, particularly around the eastern shores of Lake Victoria (Fig. 22) and the coastal strip of East Africa. Hence, perspectives brought

together from past environmental and archaeological archives can provide spatially constrained, long term land-cover and land-use reconstructions that can be used to test models of vegetation and environmental change, and feed into fully coupled, next generation climate and Earth system models to provide a more comprehensive

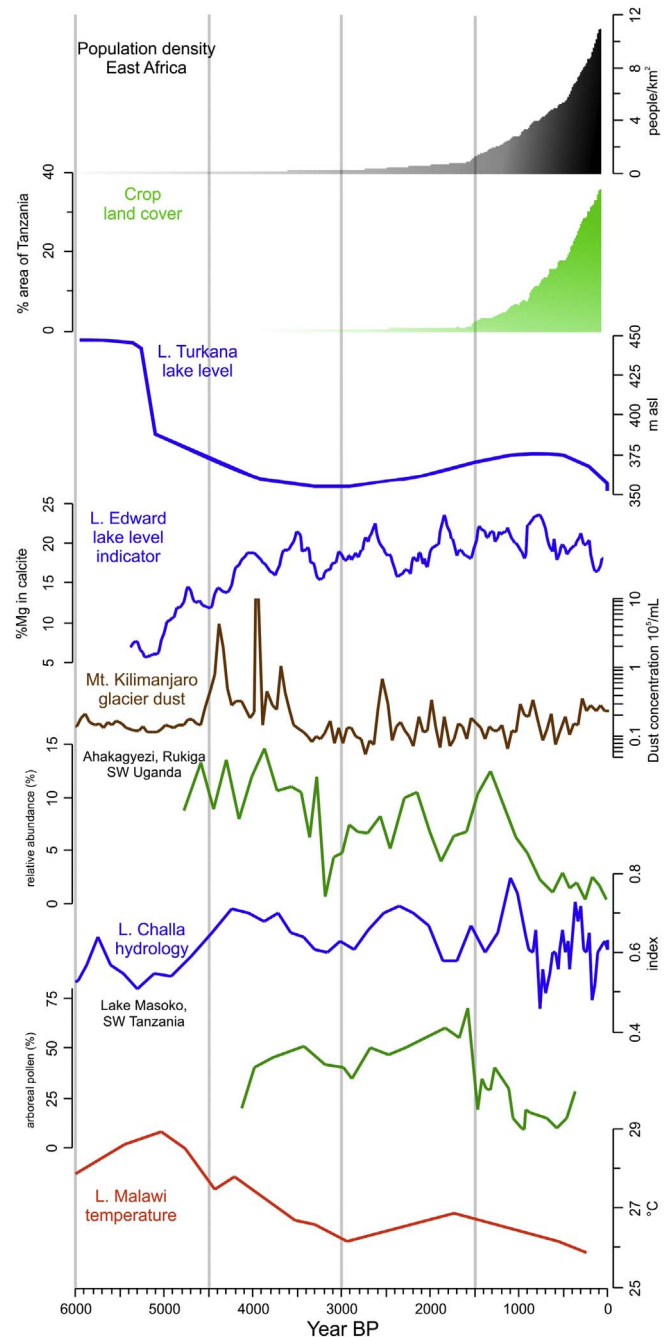


Fig. 21. Selected late Holocene palaeoenvironmental records from eastern Africa. The graphs are described here from top to bottom of the page: Modeled reconstructions of historical population and cropland coverage estimates (KK10; Kaplan et al., 2011 and Kaplan and Krumhardt, 2011). Lake level reconstructions for interpreting hydroclimatic variability from Lake Turkana (Garcin et al., 2012) and Lake Edward (Russell et al., 2003). Kilimanjaro northern ice field dust concentration reconstruction as a proxy for vegetation cover in the lowland dust-entrainment source areas (Thompson et al., 2002). Afromontane pollen sums (% total pollen) as a proxy of forest cover from Ahakageyezi Swamp, Rukiga Highlands, Uganda (Taylor, 1993). Lake Challa hydroclimate reconstruction using BIT (Verschuren et al., 2009). Temperature reconstructions from Lake Malawi (474 m asl; Powers et al., 2005; Loomis et al., 2017); and re-digitised arboreal pollen relative abundance (%) as a proxy for tree cover from Lake Masoko sediment record (Thevenon et al., 2003; Fig. 6).

Land use / land cover change in the East African Community

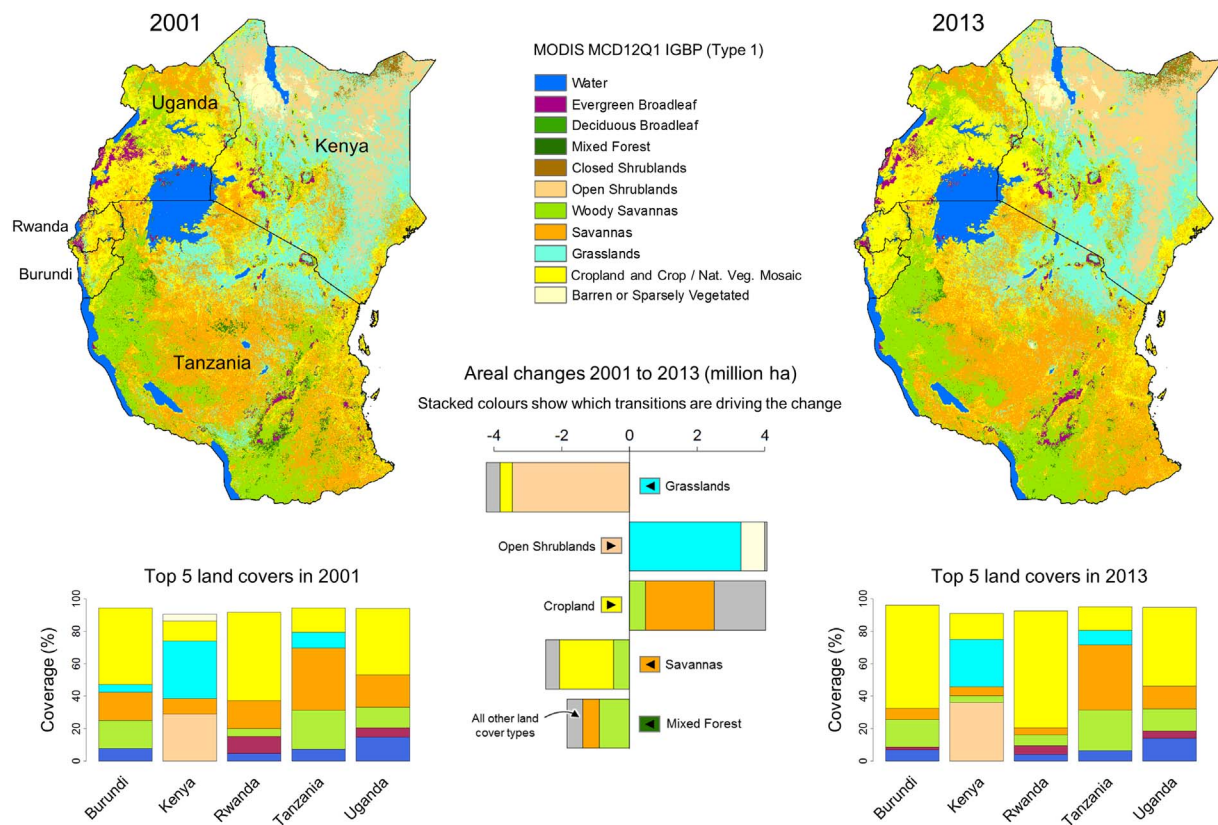


Fig. 22. A comparison of recent land use change across East Africa derived from paired MODIS satellite images. Particularly clear is the recent expansion of the agriculture land class around Lake Victoria and the coastal strip of East Africa.

understanding of environmental-human interactions and how these change over time and across space.

5.3. Enhanced understanding of ecosystem services and biogeochemical cycling

Ecosystems and the services they provide (e.g., food, timber, water, carbon storage, nutrient cycling, soil formation, etc.) are fundamental for future livelihoods (Rockström et al., 2009). This relationship between people and natural resources is particularly close across East Africa where people's livelihoods connect strongly with their environment (Fig. 23). It is therefore of critical importance to the management of ecosystem services – both in the present and in the future – to understand how they have, and do, vary temporally and spatially (Dearing et al., 2014). Challenges to this relationship come in the form of climate change, land-use transformation, population growth and migration, and complex local to global environmental policies. Population growth together with socio-economic development unavoidably results in resource competition between different land-use requirements (e.g., agriculture, forest and biodiversity conservation, pastoralism, water provision and carbon sequestration). Compounding these biophysical challenges are challenges around developing and implementing workable Payment for Ecosystem Services (PES) schemes that are often run at international (e.g. Reducing Emissions from Deforestation and forest Degradation (REDD) and REDD+), national (e.g., Participatory Forest Management) and local (e.g., agri-environment accreditation) scales.

Human-induced land-use change can impact on the underlying ecosystem services, especially via altering biogeochemical cycles and the composition and distribution of ecosystems (Pagel and Mace, 2004). The integration of these long-term records into planning and

ecosystems management tools is vital for the future provisioning of ecosystem services (Jeffers et al., 2015). An understanding of land-use change can support policies aimed at mitigating both the driving factors behind such change, and the behaviour of complex agro-ecosystems under changing conditions (de Koning et al., 1999). For example, in East Africa it is clear from palaeoecological and historical evidence (Section 3) that precipitation regimes can change suddenly and they are not synchronous across the region, therefore future adaptation planning would be wise to include provision for such variations (Shanahan et al., 2015). Impending changes in environment, population, land use, and economic development in the near future will dictate patterns of water supply and demand (Vörösmarty et al., 2000). Wetland environments have clearly figured prominently in East Africa throughout the last 6000 years and continue to be important to many societies: such environments are, and were, attractive areas within a landscape due to their high diversity in resources, high productivity and their reliable water supply (Nicholas, 1998). As population continues to grow, and as the regional climate seasonality becomes enhanced, there is increasing pressure on water supplies (Platts et al., 2015); this pressure is accentuated further as freshwater supplies become even more restricted due to pollution (Vörösmarty et al., 2000; Heathwaite, 2010). Jeffers et al. (2015) and Ekblom et al. (2017) identify palaeoecology as being ideally situated to address questions around vulnerability in water supplies under differing climate change scenarios, and also for potentially providing baseline information on water supply and quality. These issues are gaining increasing importance as government agencies around the world, but particularly in East Africa, become responsible for implementing legislation to ensure the reliable and clean water supplies exist and are maintained.

The recent study by Jeffers et al. (2015) also identifies three factors

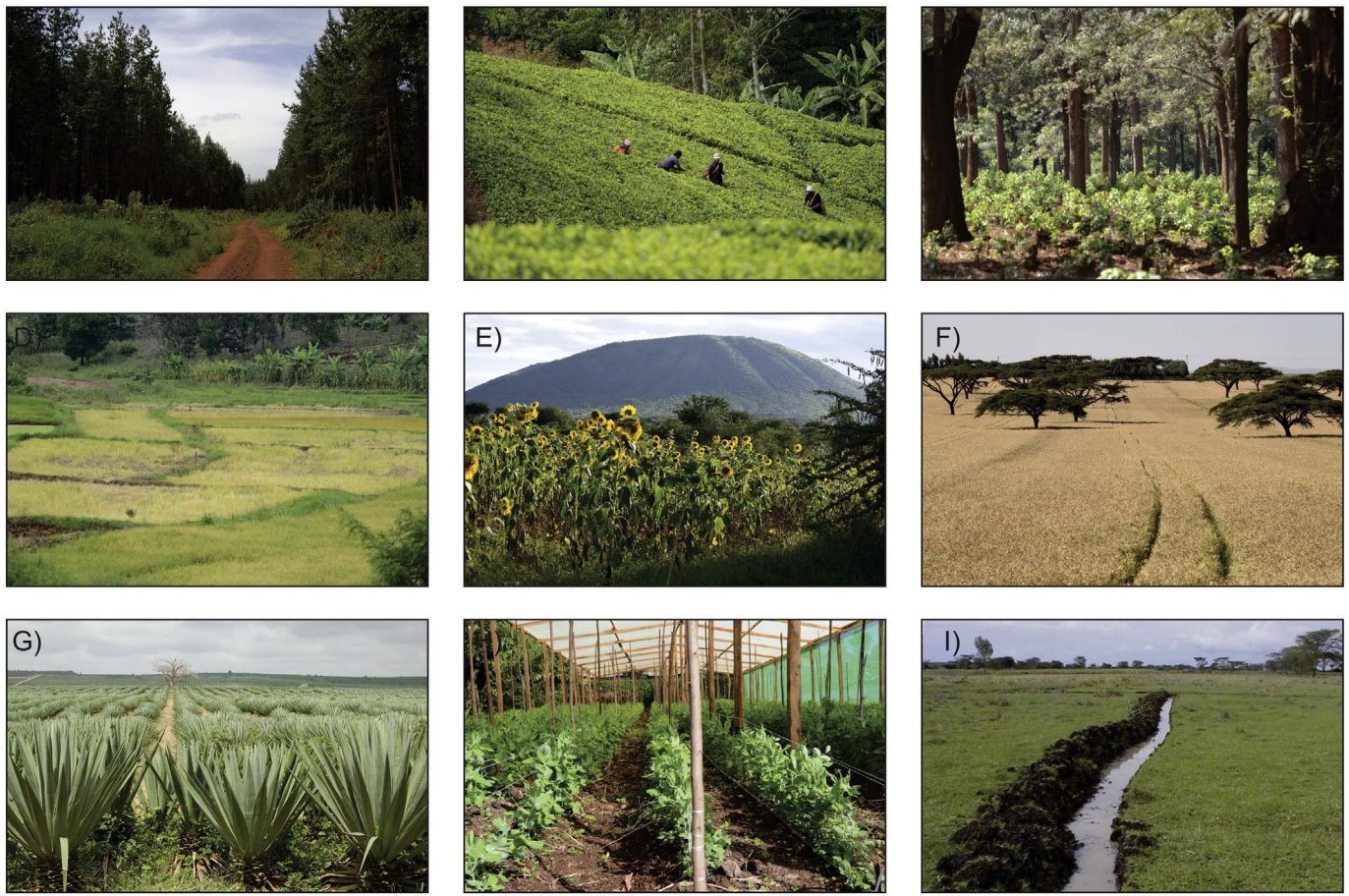


Fig. 23. Land cover for agricultural production. A) Agroforestry of exotic pine trees (*Pinus*) on the slopes of Kilimanjaro (photo: Rob Marchant). B) Tea farms on the slopes of Mount Kenya (photo: Rob Marchant). C) Coffee plantation showing mixed vegetation structure of coffee shrubs shaded by quick growing exotic *Eucalyptus* on the edge of the Ngorongoro Highlands (photo: Rob Marchant). D) Rice paddy fields in the Tana River (photo: Rob Marchant). E) Sunflower cash crops (photo: Rob Marchant). F) Wheat field with acacia trees (Fabaceae), which provide nitrogen to the soils in Narok County, Kenya (photo: Rob Marchant). G) Sisal farming on the Kenyan coast (photo: Rob Marchant). H) Tomato farming in covered market garden (photo: Rob Marchant). I) Irrigation channeling from spring-fed wetlands in eastern Amboseli, southern Kenya (photo: Esther Githumbi).

that underpin ecosystem services, changes in which will ultimately affect the provisioning of ecosystem services today, and in the future in East Africa. The three factors are the availability of nitrogen and phosphorous; plant biomass and soil. Understanding the history of these has been possible in other parts of the world through the use of palaeoecological proxies. Nitrogen levels in the environment are particularly elevated because of the use of fertilisers and crop farming strategies (example Fig. 23F), and this is seen clearly as pollution in East African lakes (Zhou et al., 2014), which in turn reduces the ability of those lakes to provide ecosystem services. Using stable isotope analysis of nitrogen ($\delta^{15}\text{N}$) from the sedimentary record (Chapman et al., 2006) allows us to track pollution both spatially and temporally, and provides the wider community with a baseline for pollution control (Jeffers et al., 2015).

The second factor identified by Jeffers et al. (2015) - plant biomass - is linked to many ecosystem services that include climate regulation, protection from soil erosion, the provision of clean water and higher yields of timber and crops (Mace et al., 2012). Understanding how plant biomass fluctuates in relation to climate change is going to be of utmost importance for future scenario modelling and as PES schemes increase across East Africa. These schemes rely on being able to model carbon drawdown and sequestration (Asner et al., 2010), which are then equated to a monetary value. Baseline information is required on the potential of the forests to sequester and store carbon, particularly where many of the previously extensive forests of East Africa have been largely converted to agricultural land. For example, the Coastal Forests and Eastern Arc Montane Forests of Tanzania and Kenya are now

restricted to a number of isolated pockets under protected area status. While we can see the impact of relatively recent (decadal) land-cover changes through remote sensing such as MODIS and other satellite-based Earth observation products (Fig. 22), again a deeper perspective is really required to provide the full picture of the potential, and to enable this potential to be realised. For example, regarding the Eastern Arc Montane Forests, a Biodiversity Hotspot of global importance (Burgess et al., 1998b), and the former palaeoecological extent of these ecosystems is thought to be some 80 to 90% greater than their current extent (Willcock et al., 2016). There is still some way to go in refining schemes implementing payment for ecosystem services: for example, the effect of fire on carbon storage (Barlow et al., 2012) has not been taken into account, and given the clear palaeoenvironmental evidence on how these fire regimes have changed through time (Courtney-Mustaphi et al., 2017) and the recent increase in wildfires (Barlow et al., 2012), it is highly probable that changes to fire regimes is a significant factor across many East African landscapes (Hemp and Beck, 2001; Colombaroli et al., 2016; Hempson et al., 2017).

Soil underpins a number of ecosystem services, such as nutrient cycling and below ground carbon storage; it is also fundamental for agricultural provision and water supply (Jeffers et al., 2015). The palaeoenvironmental and archaeological records provide information that can inform and validate soil formation and erosion models. Analysis of soil formation is undertaken by examining fluctuations in the rates of soil evolution, seen through pedogenic changes over time. These pedogenic changes occur in response to local factors such as changes in vegetation cover and land-use cover, and also in relation to climate

change. An example of where pedogenic changes have been observed through detailed archaeological soil analyses comes from the site of Engaruka in northern Tanzania (Lang and Stump, 2017), here pedogenic changes have occurred through changes in land-use practices, namely agriculture and irrigation. Lastly, erosion and influx of mineral organic matter can be inferred from soil analysis, but also from geochemical analyses (Hu et al., 2001). Human activities and climate change can accelerate soil erosion processes, which, in turn, are likely to produce an economic effect as productive agricultural land becomes lost and water quality declines.

5.4. Understanding current biodiversity patterns and links to current conservation challenges

East Africa is world famous for the National Park network that brings in vital tourist revenue across the region. The Tanzania and Kenya Borderlands region is home to fourteen protected areas, that include the Amboseli, Masaai Mara and Serengeti National Parks; these alone attract millions of visitors per annum with billions of US\$ in associated tourist revenue that is vital to the national economies (Fig. 24E). Climate change, and how this will impact on ecosystems, is highly uncertain, likewise, the associated impacts on biodiversity, protected areas and socioeconomic benefits are largely unknown. For example, within the Amboseli National Park in southern Kenya, the extensive drought experienced in 2008–2009 resulted in a 90% reduction in the wildebeest populations, and corresponding reductions in

the populations of other ungulates (David Western, unpublished data; Okello et al., 2015). Despite this decrease in ungulates, carnivore populations increased at this time, however, in the absence of wild ungulates the domesticated livestock of the pastoral communities, such as cattle, sheep and goats, came under pressure from predation instead (Manoa and Mwaure, 2016). In order to control this spiralling human-wildlife conflict, the Kenyan Wildlife Service spent approximately US\$ 1,000,000 on 150 zebra from a private game reserve in Kenya to alleviate the pressure. Whilst this is clearly unsustainable into the future longer term, perspectives from the longer-term past may be able to guide more informed decisions in the future. One of the key findings from the work on the environmental histories of East African savannahs has been the large and rapid fluctuations in wetlands, driven by regional hydrological variability. This variability has had massive impacts on water and grazing refuges during periods of drought, and will do so in the future as pressures on these resources intensify due to fragmentation and increasing human populations. More broadly, whilst these hydrological fluctuations are now known about in general, the detail is lacking in many instances. We still need to understand the mechanisms and triggers for the origins of wetlands; how they are hydrologically sustained and how the climate can affect these fragile ecological systems. Whilst we do not know how most swamps are hydrologically sustained, they currently serve as a permanent freshwater source for animals and people, and as such are critical for maintaining biodiversity (Homewood and Lewis, 1987). Another example is that of spring-fed wetlands that are vitally important resources and connectivity nodes in

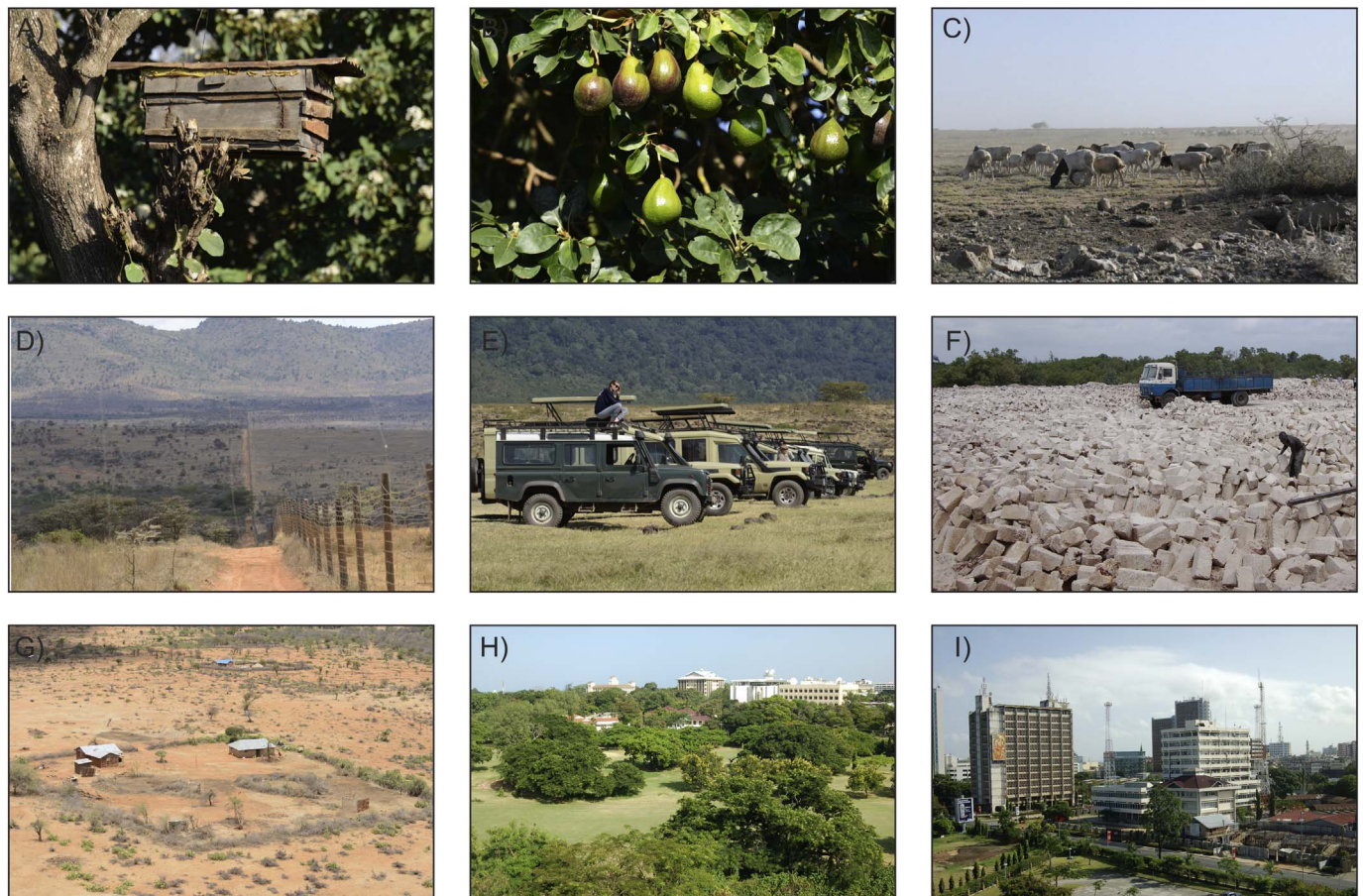


Fig. 24. Land cover and land use for diversified livelihoods. A) beekeeping for honey collection and important to flowering plants and crops (photo: Rob Marchant). B) Fruit production on trees planted in household gardens, this example shows avocado fruit (*Persea americana*) introduced from central America (photo: Rob Marchant). C) Pastoralism near Oldupai, Tanzania (Photo: Colin Courtney-Mustaphi). D) Fenced areas to separate conservation estate (left) with open grazing (photo: Rob Marchant). E) Safari tourism and game viewing is a major industry and contribute a significant part of delivering foreign income (photo: Rob Marchant). F) Stone surface quarrying for building materials on the Kenyan coast (photo: Rob Marchant). G) Pastoral villages with traditional thorn fencing. H) Wildland-urban interfaces, Nairobi (photo: Rob Marchant). I) Urban land cover mosaic, Nairobi, Kenya (photo: Rob Marchant).

arid regions of East Africa, not only for providing cooking and drinking water, but also for providing materials for fodder, thatching roofs and for mat making (Ashley et al., 2002; Cuthbert et al., 2017). However, these spring-fed wetlands are increasingly being put under pressure as population increases (e.g., Thenya, 2001).

As these pressures continue to intensify and modify areas, there is a need for policies and practice to promote successful adaptation strategies. Before this can occur, an appreciation is needed about how people perceive climate change, their current adaptation measures, and other factors that may influence decisions to adapt current practices. Again, salutary lessons can be learned from a historical perspective. Meeting, and addressing, the challenges that East African ecosystems face in a world of rising populations makes the need to understand human–environment interactions (past, present and future) more pressing, particularly because it is only through people – from local communities to policy makers – that a sustainable mode of human–environment interaction will be desired, implemented and hopefully achieved. A longer-term perspective on land-use change that also brings together conservation measures to assess the challenges to biodiversity conservation and to provide status assessments would be a helpful step forward. A good example of the utility of this long-term perspective is clear from our understanding of fluctuating elephant populations. After the ban on international trade in ivory from 1989 (Lemieux and Clarke, 2009) poaching dramatically declined. However, despite this relatively instant reduction, we still know relatively little about the effects of changing herbivore numbers, and there is still an urgent need for more data on long-term vegetation variability in response to changing herbivore densities. Gaining insight on this relationship would have the effect of improving our understanding of ecological processes in savannahs; past distribution of elephant populations (Coutu et al., 2016); and their mobility patterns and geographical ranges (Coutu, 2015). And crucially, it could also provide a basis for future management decisions. We know today the significant impact that elephant populations have in maintaining open and grassland (Morrison et al., 2016), and that the

impacts of these important ‘ecosystem engineers’ has been significantly curtailed through the wholesale removal of the elephant population from some areas, initially through the European and American-driven demands for ivory during the 19th and early 20th centuries, and now, owing to the recent upsurge in poaching and illicit trade in ivory, largely driven by Asian markets (Sommerville, 2016). Integrated, multi-sited, landscape historical and political ecologies of these trades and previous phases of forest and savannah elephant ivory extraction offer one model for addressing these challenges (Håkansson, 2004; Lane, 2010).

Understanding how people have interacted with their environments in the past, in particular in savannah landscapes that dominate the main areas of archaeological and palaeoecological work to date, is important today; but has been (and still is) a dynamic, complex and ever-changing interaction. But it is precisely these complex relationships that have shaped the productive and varied biome of savannahs that we see today. In line with Fairhead and Leach's (2000) argument, it is only by understanding these landscape histories of savannahs that we can move beyond narratives of degradation to one where societies are interwoven with the ecosystem. This flattening of the hierarchy of knowledge construction allows the possibility for multiple voices within the landscape to be heard and recognised, including those from palaeoecology, archaeology and local communities (Richer and Gearey, 2017b). However, as a result of these complex interactions, the rate of change in savannah landscapes is potentially faster and more dramatic than we have witnessed before, as can be seen through events such as species extinctions (Maslin, 2016). Trying to gain clarity on the inter-linkages between societal and ecological processes, such as habitat fragmentation and human–animal conflict, is becoming increasingly pressing to ensure the livelihoods of people currently living in these landscapes (Marchant, 2010).

Indeed, a more balanced view that biodiversity is part and product of complex and linked natural anthropogenic interactions (Pinedo-Vasquez et al., 2002) is crucial if we are to manage ecosystems in a

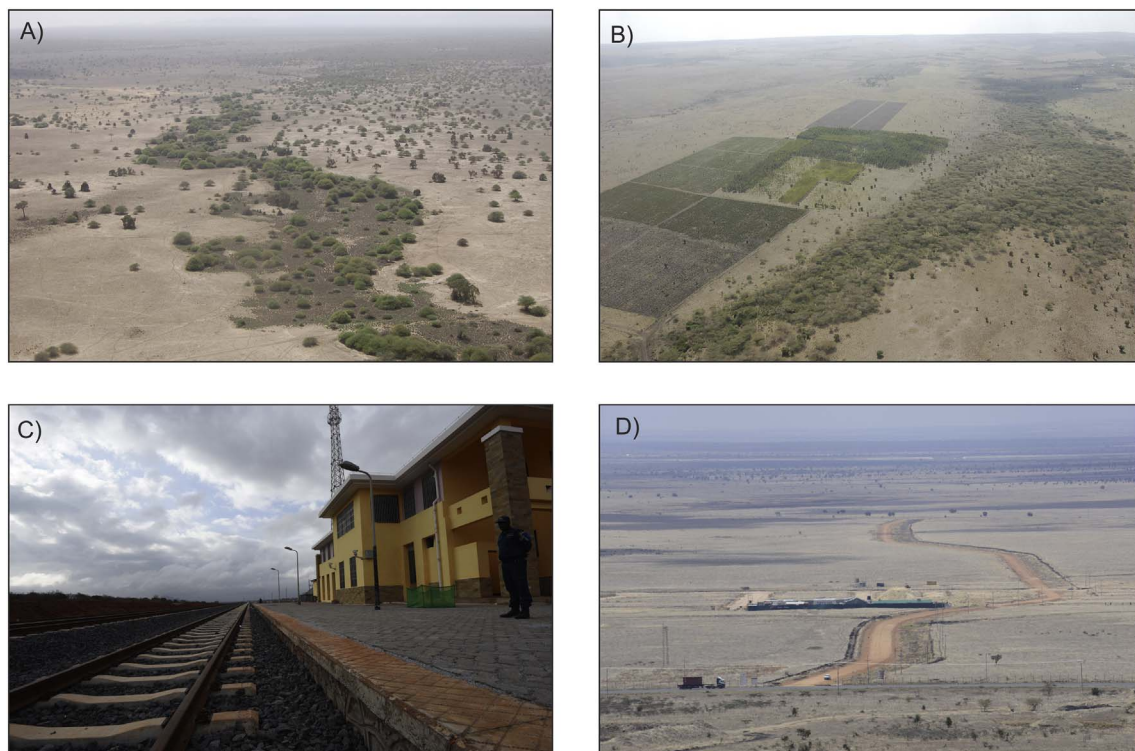


Fig. 25. Land cover mosaics and linear features. Riverine gallery forest through semi-arid savannah-woodlands north of Amboseli. B) Landscape heterogeneity where irrigated agriculture has developed along a river course close to Nairobi. C) New infrastructural developments: the standard gauge railway from Nairobi to Mombasa. D) New infrastructural developments: Technology city in the making. All photos by Rob Marchant.

future of uncertain change. For example, the diversity in resource use, cultural practices and the capacity of adaptations for social change are only rarely taken into account for conservation and development schemes (Pinedo-Vasquez et al., 2002). There is nevertheless a growing realisation that the idea of virgin rainforests, initially seen as largely ‘untouched’ by ‘native’ people, is a misnomer (Willis et al., 2004). Instead, the extent of, and potential relationships between, early populations and ecosystems, is supporting the realisation that humans have sculpted closed forest for millennia (Pearce, 1999; Roberts et al., 2017). With long-term perspectives on human-ecosystem interaction we can modify our conservation and protectionist ethos to adopt more dynamic strategies for conserving biodiversity to accommodate the change that inevitably occurs in species ranges and environmental regimes over time (Tallis, 1991; Marchant, 2010). Conserving ecosystems and communities as they presently exist, or intervening to restore them to a previous state, has become redundant. Instead, dynamic strategies are supported as these can allow for a type of conservation that accommodates climate change by embracing concepts that encapsulate networks and connectivity – as these can support fluidity and change (Hannah et al., 2002a). Given current climate projections (Platts et al., 2015), conservation institutions and approaches will fail if they do not factor in change as major component of the system. Equally, individuals, communities and societies will also need to be able to adapt and change, to reduce their vulnerability to climate change (Rayner and Malone, 1997). It is also the responsibility of the academic community to rethink how we research and communicate our understandings of climate change, and this includes challenging our current theories and models for working on issues surrounding climate change and how people and environment relate (Rayner and Malone, 1997; Marchant and Lane, 2014). An example of this is the debate about paved roadways through the Serengeti ecosystem (Dobson et al., 2010; Homewood et al., 2010; Fyumagwa et al., 2013) and development of new railways lines; both of which are long linear features that fragment landscapes and have varied socio-ecological benefits and impacts (Fig. 25) (Hopcraft et al., 2015). One of the many ways that we can engage with the call to radically alter how we think about these issues is to again reiterate the importance of relevant and scientifically robust palaeoecological and archaeological records.

5.5. Further research

Along with population growth (Canning et al., 2015) and anthropogenically-induced land use and land cover changes (Schmitz et al., 2014), climate change adaptation is amongst the greatest future challenges for many African countries (Niang et al., 2014; Gasparatos et al., 2016). Understanding past interactions between past ecosystem dynamics, movements of people and land-use strategies is paramount if we want to understand the relationship between human societies and climate change; this requires going beyond individual site records that remain entrenched in only one discipline, and instead undertaking integrated landscape-scale research (Dillehay, 2002). It is such an approach that is the foundation of this paper. Characterising the emergence of a diversified agriculture and rapid spread of crops across East Africa is one of the most challenging research topics for the future (Neumann, 2005), and not only because the identification of pollen of indigenous cultivated crops is challenging, although this is certainly one area that needs addressing. Enhanced collaboration between the palaeoenvironmental and archaeological communities will help to provide an integrated perspective on this crucial period in the recent history of East Africa. And whilst landscape-wide studies are needed, there is a simultaneous need for high-quality, high-precision and high-resolution records within this (cf. Ssemmanda et al., 2005; Russell et al., 2007, 2009; Bessems et al., 2008). From a palaeoenvironmental perspective, one of the key locations to obtain the material for such analyses is from the so far largely untapped resource of small lakes and sedimentary basins. Once these sites have been identified, the next step

is to provide a robust, accurate and precise chronology to their respective sequences. In the majority of case studies, the timing, frequency, magnitude and regional phasing of these events is poorly understood. There is thus a need, not only for more well-dated sequences, but for sample selection to be made intelligently using predictive modelling prior to sample submission, and for dating determinations to be further constrained using appropriate Bayesian methodologies. Whilst these methods do not provide ‘the answer’, they allow for us to gain a better understanding of temporal variation, which is vital in any understanding of climate conditions in eastern Africa.

However, even when a robust chronology has been constructed, we are still in need to disentangle the non-linear relationships between precipitation-fire-vegetation (Whitlock et al., 2010; Lehmann et al., 2014; Njokuocha and Akaegbobi, 2014) and also the feedbacks between them (Cochrane et al., 1999). This is especially important in East African savannahs due to the difficult nature of assessing whether changes in precipitation or land use have caused the shift in fire regimes (Stocker et al., 2013). Similarly, there is also a need for an increased number of higher-temporal-resolution palynological studies within East Africa, particularly those that place an emphasis on multiproxy methodologies. Whilst we still need to devise new methods to aid in differentiating climatic and anthropogenic signals, the more information we have at our disposal to undertake this means that we can use this information in a Bayesian-like manner to begin to refine our interpretations and place more certainty on whether we are witnessing anthropogenic, climatic or mixed signals in the palaeoecological record.

6. Conclusions and prospects

Throughout our synthesis a wide body of information has been presented from two different schools spanning the environmental and human sciences and we have indicated the possible interrelationships between these independent findings. Climatic conditions in East Africa have varied throughout the Holocene, and the only constant that can be identified is that of change. The tendency of climate to change relatively suddenly, often over the scale of a single generation, would have been highly noticeable to human populations, and may have offered both difficulties and opportunities. We cannot know how people perceived these climatic changes in the past, but by the same measure, researchers worldwide have yet to fully consider the potential implications of the sudden environmental changes that would have occurred as the result of both climatic and anthropogenic drivers. Throughout this review we have identified patterns that exist in the current datasets and where the different types of evidence corroborate or contradict one another, and have highlighted how the lack of spatial or chronological resolution or contrasting resolutions between datasets hamper this effort. Although the amount of data, and the spectrum of techniques applied from these foci, has greatly increased over the last couple of decades, many gaps still remain and the evidence carries the historic legacy of being biased towards certain key sites and time periods; other areas and time frames may need to be targeted by new initiatives.

Integrating information from different disciplines, with independent ontologies, methodologies, vocabularies, and interpretative frameworks is not a straightforward task, but will enhance our understanding of past environmental change and how people have been enmeshed within this process. It is unlikely that this understanding will be fully realised, but in working towards it we need to apply the currently underutilized theories, methodology and techniques that we have at our disposal; such as non-pollen palynomorphs, grass cuticles, seeds, geochemical analysis, charcoal and phytoliths (Alexandre et al., 1997). Changes and advances in theoretical positions, techniques, rigorous sampling of a greater number of sites, together with greater applications of GIS and modelling may nudge the enquiry into new domains. However, the main concern is the shortcomings of our current explanatory strategy, which leaves many questions still remaining to be answered. These will

hopefully be explored through new datasets and through further analyses of the metadatasets presented here.

Understanding differences in the intensity of environmental change signals in different parts of the world informs us of some of the underlying global climate dynamics. In turn, this can help to enhance our predictions of future likelihoods of rapid climate change, and some of their associated societal impacts. More broadly, this underlies the need to move away from orthodox, Eurocentric, notions of human–environment inter-relationships (Morrison, *in press*; Richer and Gearey, 2017b) and to rethink the changing relationship between nature and humans in the past as well as in the future. This is especially the case as human action comes to modify, dominate or sometimes replace natural ecosystems, and with that comes the concomitant increase in vulnerability to climate changes or extreme events (Messerli et al., 2000). Certainly, a thorough understanding of past environmental cultural dynamics is crucial to contextualising the location of protected areas and forms of land management required today. The course of human history is closely coupled with that of the environment; the same holds true for the African continent's future. Indeed, the contribution of palaeoecology and archaeology is not to 'simply' reconstruct the past but to confront the present (Hassan, 2000). Additional insights from combining research from different disciplines may lead to a retrospective process to examine how well the individual disciplines are poised to answer future research questions.

The frequency of atypical weather extremes linked to anthropogenically induced climate change is projected to increase in frequency and magnitude (REF). The disruption of traditionally predictable seasons, including increased frequency of extremes (droughts and floods) as seen throughout the world, has major implications for crop yields and livestock, and hence for the social structure of pastoralists and farmers (Brown, 1971). Creating knowledge and integrating past datasets into future planning and policy is a central output of this review: identifying a range of practices that may enhance community and ecosystem resilience and adaptive capacities (Holling, 1973) that could be incorporated into landscape planning and future scenarios is a crucial development. A better understanding of how people have responded to past environmental change, and how ongoing adaptation measures have evolved, are vital if we are to craft visions, policies and programmes aimed at promoting successful adaptation to future environmental shifts and cultural changes. Datasets currently under production and synthesis will also be crucial in providing baselines for building future scenarios based on the range of variability and potential threshold responses, and as valuable information for decision making in land management, food production and security. Planning for the long-term sustainable use of natural resources requires a long-term perspective on human–ecosystem–environment interactions and engagement with the biocultural heritage and societal evaluations of these spaces to achieve an increasingly diverse set of conservation, social and economic objectives. Whilst critical earth system boundaries have been identified and exceeded at the global level, most sustainability targets (e.g. Sustainable Development Goals) either remain unmet, or appear highly challenging to achieve. We contend this is in part because there is little synthesised knowledge of environmental, social and heritage interactions at the landscape or catchment scale. Our cross-disciplinary socio-environmental review presents how East African social-ecological systems have responded to environmental and social shifts in the past, and will hopefully contribute to informing how ecosystems, people and wildlife will respond in the future.

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